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SEPTEMBER 1915

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THE ECLIPSING VARIABLE STAR δ ORIONIS

By JOEL STEBBINS

Among the stars which from time to time have been suspected of variability is δ Orionis, the faintest of the three in the belt of Orion. This object has been in and out of the variable star catalogues, and observers have been unable to agree whether or not there are any changes in brightness. As far as is known to the writer, the star has never been exhaustively studied with a photometer, and we have only the results from estimates with the unaided eye. When the selenium photometer was first being tested, among the most favorable objects were seen to be δ, ε, and ζ Orionis, as these are of the same spectral type, of about the same brightness, and near enough together so that the correction for atmospheric absorption is small. Numerous attempts were made, but the measures for a considerable period were tests of the constancy of the instrument rather than observations of the stars. At last, in the early part of 1910, serious measures were undertaken, but the results were not accordant. It was assumed that any short-period light-variation of δ Orionis would be synchronous with its spectroscopic period, 5.7325 days. On this assumption the observed magnitudes were arranged according to phase, and it looked as though the comparison stars were not constant, that the suspected variable was irregular, or, what seemed more probable, that there was some

undetermined source of instrumental error present. The observing season of 1909–1910 passed without the chance to clear up the trouble, but the following winter the observations were taken up in earnest. Another discordant measure making δ Orionis unusually faint was found to come just at the eclipse time as predicted from the spectroscopic elements, and the previous observations were therefore re-examined. On checking up the reductions, it was found that a mistake of two days had been made in transcribing the date of one of the observations, and with this correction it was seen that all of the evidence pointed to the fact that δ Orionis is an eclipsing variable with the times of two minima in accordance with the spectroscopic orbit.[1] Further observations established this discovery beyond the possibility of a doubt, and it was determined to derive the best possible light-curve.

It is probable that the early eye-estimates of the variability of this star cannot be brought into agreement with the new light-curve. As the total range turns out to be only 0.15 mag., and the two stars near by are about half a magnitude brighter, the variation would be practically impossible to determine. So far as my own eye is concerned, I am sure that the light-changes are entirely imperceptible, for I have looked at the star time after time when I knew it was near a minimum, but I could see no change whatever from normal brightness.

The spectroscopic orbit of δ Orionis was worked out in some detail by Hartmann,[2] but he did not make a least-squares solution for the elements. In view of some discrepancies between the photometric and spectroscopic results, the present work, which was completed in 1912, has been held until a new orbit should be available. Professor R. H. Curtiss took up spectrographic observations at Ann Arbor and has kindly sent me his unpublished results. In the meantime, another orbit has been worked out by Jordan[3] at Allegheny, who also has made a least-squares reduction of Hartmann's observations. We have therefore three sets of elements, all independent. For the purposes of this paper, any one of the orbits may be selected, but as all of the reductions were made when only Hartmann's first elements were available, these computed

[1] *Astrophysical Journal*, **34**, 111, 1911. [2] *Ibid.*, **19**, 268, 1904.

[3] *Publications of the Allegheny Observatory*, **3**, 125, 1914.

phases for the observed and normal magnitudes have been retained. In the further discussion of dimensions of the system, the results of Curtiss have been used.

TABLE I

SPECTROSCOPIC ELEMENTS AND TIMES OF MINIMA

	Hartmann	Hartmann (Jordan)	Jordan	Curtiss
P	$5^d.7325$	$5^d.7325$	$5^d.7325$	$5^d.732448$
T_0 J.D. 241	5793.35	5793.756	8981.295	9806.383
e	0.103	0.096	0.085	0.0983
ω	339°.3	4°.9	20°.4	359°.33
K	100.8 km	100.12 km	99.98 km	100.96 km
γ	+ 23.1 km	+ 22.85 km	+ 15.20 km	+ 20.15 km
Min. I., J.D. 241	9068.190	9068.196	9068.248	9068.162
Min. II–Min. I	$3^d.218$	$3^d.215$	$3^d.157$	$3^d.224$

The journal of observations is given in Table II. In the first series of 1910, the measures were taken of δ, ε, and ζ Orionis, and δ is therefore referred to the other two, but after that only ε was used for a comparison star, and the entire series is practically homogeneous. The phase was reduced to the sun, though this was

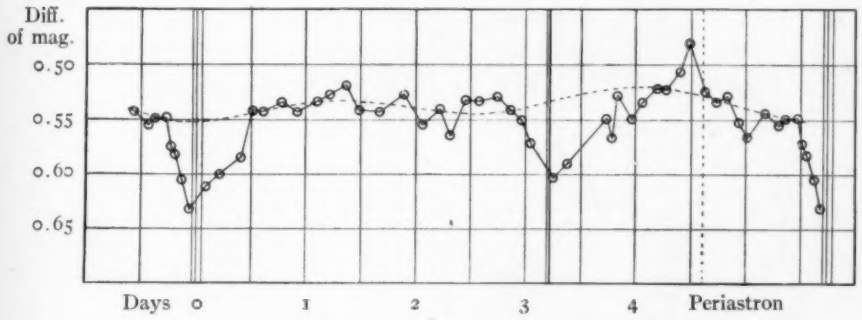


FIG. 1.—The light-curve of δ Orionis

probably unnecessary. The difference of magnitude is in the sense: δ *minus* ε. A "set" of measures usually consisted of two exposures on the comparison star, then six on the variable, and finally two on the comparison star. Under ordinary conditions, it was possible to observe at the rate of five sets per hour. The residuals, rounded off to hundredths of a magnitude, were obtained graphically from the irregular curve shown in Fig. 1.

TABLE II

OBSERVATIONS OF δ ORIONIS

Date			G.M.T.	Phase	Difference of Magnitude	Sets	Residual Obs.−Curve
					mag.		mag.
1910	January	9.....	17^h07^m	$3^d.338$	0.576	2	−0.02
		18.....	16 34	0.850	0.525	2	− .02
		27.....	17 01	4.136	0.485	2	− .04
	February	1.....	17 01	3.402	0.549	2	− .04
		3.....	15 25	5.335	0.552	2	0
		4.....	16 43	0.658	0.545	2	0
		6.....	15 05	2.589	0.517	2	− .02
		12.....	16 02	2.896	0.509	2	− .04
	October	10.....	21 42	2.366	0.528	5	− .03
		11.....	21 41	3.365	0.587	5	0
		13.....	21 34	5.362	0.544	5	− .01
	November	7.....	20 33	1.658	0.549	5	+ .01
		11.....	20 48	5.669	0.665	5	+ .03
		11.....	21 55	5.715	0.637	5	+ .01
		17.....	19 01	0.130	0.582	4	− .03
		19.....	19 15	2.140	0.559	5	+ .01
		21.....	20 51	4.207	0.525	5	0
		21.....	22 08	4.260	0.511	5	− .01
		28.....	20 55	5.477	0.533	5	− .02
		29.....	18 56	0.662	0.541	5	0
		29.....	19 30	0.685	0.557	5	+ .02
	December	7.....	17 49	2.883	0.518	5	− .02
		7.....	18 47	2.924	0.543	5	0
		7.....	19 45	2.964	0.535	5	− .02
		7.....	20 42	3.003	0.553	5	0
		7.....	21 42	3.045	0.571	4	0
		10.....	15 18	0.045	0.605	5	− .02
		10.....	16 26	0.093	0.623	5	+ .01
		10.....	17 25	0.134	0.627	5	+ .02
		10.....	18 24	0.175	0.603	5	0
		10.....	19 42	0.229	0.575	6	− .02
		11.....	17 59	1.157	0.525	5	− .01
		13.....	16 35	3.099	0.562	5	− .02
		13.....	18 31	3.180	0.608	5	− .01
		13.....	19 30	3.220	0.593	5	− .01
		13.....	20 30	3.262	0.600	5	0
		13.....	21 26	3.301	0.625	4	+ .03
		14.....	17 02	4.118	0.537	5	0
		14.....	18 02	4.159	0.511	5	− .01
		20.....	17 53	4.419	0.511	5	0
		20.....	18 51	4.460	0.478	5	− .01
		26.....	17 02	4.653	0.543	5	+ .02
		26.....	18 00	4.693	0.520	5	− .01
1911	January	3.....	18 49	1.262	0.558	5	+ .03
		4.....	19 07	2.275	0.511	5	− .05
		4.....	20 05	2.315	0.560	5	0
		8.....	16 21	0.426	0.585	5	0
		8.....	17 21	0.468	0.601	5	+ .04
		8.....	18 20	0.510	0.579	5	+ .03
		22.....	17 36	3.013	0.553	2	− .01
		29.....	17 50	4.289	0.500	5	−0.02

TABLE II—*Continued*

Date			G.M.T.	Phase	Difference of Magnitude	Sets	Residual Obs.−Curve
					mag.		mag.
1911	February	1.....	$15^h\,21^m$	$1^d.453$	0.543	6	+0.01
		9.....	17 29	3.809	0.557	5	0
		22.....	16 38	5.308	0.570	5	+ .02
		23.....	16 37	0.573	0.556	6	+ .01
		24.....	16 12	1.556	0.510	5	− .03
	March	4.....	14 44	3.762	0.572	5	0
		4.....	15 42	3.802	0.574	5	+ .01
		24.....	14 22	0.816	(0.589)	5	(+ .05)
	September	29.....	21 37	0.948	0.523	5	− .02
	October	11.....	21 02	1.458	0.528	5	− .01
		12.....	21 58	2.497	0.530	5	0
		14.....	19 42	4.404	0.511	5	0
		14.....	20 48	4.450	0.501	6	+ .01
		15.....	20 45	5.448	0.590	3	+ .04
		15.....	21 57	5.498	0.601	4	+ .04
		17.....	20 35	1.709	0.554	5	+ .01
		17.....	21 35	1.750	0.558	5	+ .02
		18.....	20 07	2.689	0.542	5	+ .01
		18.....	21 05	2.729	0.531	5	0
		18.....	22 03	2.770	0.524	5	− .01
		22.....	21 37	1.020	0.501	5	− .04
		22.....	22 45	1.067	0.522	4	− .02
		23.....	21 35	2.018	0.542	5	− .01
		23.....	22 34	2.059	0.539	5	− .01
		24.....	20 45	2.984	0.568	5	+ .02
		24.....	21 44	3.025	0.586	5	+ .02
		28.....	19 35	1.203	0.530	5	0
		28.....	20 35	1.245	0.499	5	− .03
		28.....	21 33	1.285	0.513	5	− .01
	November	1.....	19 16	5.190	0.526	5	− .02
		1.....	20 14	5.230	0.530	5	− .02
		1.....	21 12	5.270	0.543	5	− .01
		1.....	22 06	5.308	0.574	4	+ .02
		1.....	22 54	5.341	0.560	4	+ .01
		14.....	18 22	0.956	0.519	2	− .02
		14.....	21 33	1.089	0.530	5	− .01
		14.....	22 33	1.131	0.546	5	+ .01
		15.....	18 36	1.966	0.533	5	− .01
		15.....	19 35	2.007	0.574	5	+ .03
		17.....	20 01	4.025	0.528	5	− .01
		17.....	21 07	4.071	0.535	6	0
		18.....	17 57	4.939	0.557	5	0
		18.....	18 56	4.980	0.556	5	0
		18.....	19 53	5.019	0.574	5	+ .01
		18.....	20 53	5.061	0.561	5	0
		18.....	21 52	5.102	0.549	5	− .01
		18.....	22 59	5.149	0.564	6	+ .02
		24.....	21 01	5.334	0.534	5	− .02
		24.....	22 02	5.376	0.544	5	− .01
		25.....	17 55	0.472	0.506	5	− .06
		25.....	18 54	0.512	0.541	5	0
		25.....	19 57	0.556	0.543	5	0
		25.....	20 57	0.598	0.532	5	−0.01

TABLE II—*Continued*

Date	G.M.T.	Phase	Difference of Magnitude	Sets	Residual Obs.−Curve
			mag.		mag.
1911 November 25	21h49m	0d634	0.536	4	−0.01
26	18 54	1.512	0.540	5	0
29	17 35	4.458	0.468	5	− .02
29	18 46	4.507	0.463	5	− .03
29	19 44	4.547	0.510	5	0
29	20 42	4.587	0.473	5	− .04
29	21 28	4.619	0.522	3	0
30	17 26	5.451	0.517	5	− .03
30	18 27	5.494	0.545	5	− .01
30	19 32	5.539	0.615	5	+ .03
December 1	19 13	0.794	0.508	5	− .03
1	20 15	0.837	0.518	5	− .02
3	20 27	2.845	0.547	5	+ .01
4	17 15	3.712	0.570	4	+ .02
5	17 01	4.702	0.505	5	− .03
5	18 07	4.748	0.549	5	+ .01
5	19 06	4.789	0.560	5	+ .03
5	20 11	4.834	0.546	5	+ .02
5	21 10	4.875	0.528	5	− .01
10	16 51	3.963	0.574	5	+ .03
10	17 47	4.002	0.564	4	+ .02
11	16 48	4.961	0.554	5	0
13	19 37	1.345	0.494	5	− .03
19	16 13	1.471	0.542	5	0
19	17 20	1.517	0.555	5	+ .01
23	17 10	5.510	0.551	5	− .01
23	18 11	5.553	0.562	5	− .02
23	19 00	5.587	0.585	4	− .01
23	19 52	5.623	0.585	4	− .02
23	20 46	5.660	0.610	4	− .02
27	15 43	3.718	0.528	5	− .02
27	16 37	3.755	0.536	5	− .02
27	18 25	3.830	0.535	5	− .01
27	19 28	3.874	0.495	6	− .04
1912 January 2	15 47	3.989	0.526	6	− .02
2	16 58	4.038	0.534	5	− .01
3	15 39	4.983	0.557	5	0
3	16 55	5.036	0.568	5	0
4	14 50	0.216	0.605	4	0
4	15 38	0.249	0.627	4	+ .03
4	16 26	0.283	0.595	3	0
4	19 29	0.410	0.564	3	− .02
4	20 05	0.435	0.560	3	− .02
6	15 15	2.233	0.566	5	+ .02
6	16 18	2.277	0.575	5	+ .02
6	17 28	2.326	0.591	5	+ .03
6	18 40	2.376	0.538	6	− .01
8	14 51	4.217	0.538	5	+0.02
8	15 57	4.263	0.548	6	+ .02
12	15 15	2.499	0.528	5	0
12	16 22	2.546	0.547	5	+ .02
12	17 18	2.585	0.543	4	+ 01
12	18 49	2.648	0.532	3	0

TABLE II—*Continued*

Date			G.M.T.	Phase	Difference of Magnitude	Sets	Residual Obs.—Curve
					mag.		mag.
1912	January	15.....	$14^h\,25^m$	$5^d.465$	0.570	5	+0.02
		15.....	15 23	5.505	0.591	5	+ .03
		15.....	16 24	5.547	0.578	5	− .01
		15.....	17 38	5.599	0.605	5	0
		15.....	18 43	5.644	0.632	5	+ .02
		15.....	19 50	5.690	0.590	3	− .04
		18.....	16 29	2.819	0.520	5	− .01
		18.....	17 54	2.878	0.570	5	+ .03
		19.....	14 41	3.744	0.565	5	+ .02
		19.....	15 41	3.785	0.559	5	− .01
		19.....	16 35	3.823	0.555	4	0
		20.....	15 58	4.797	0.506	5	− .02
		20.....	16 56	4.838	0.532	5	0
		20.....	17 53	4.877	0.536	5	0
		22.....	17 44	1.139	0.533	5	0
	February	7.....	14 03	5.518	0.542	4	− .02
		7.....	14 46	5.548	0.567	4	− .02
		7.....	16 24	5.616	0.606	4	− 0
		8.....	14 37	0.810	0.553	5	+ .02
		8.....	15 38	0.852	0.577	5	+ .04
		8.....	16 34	0.891	0.598	4	+ .06
		9.....	15 22	1.841	0.513	5	− .02
		9.....	16 26	1.886	0.547	4	+ .02
		9.....	17 20	1.923	0.519	5	− .01
		27.....	13 22	2.558	0.516	4	− .02
		29.....	14 09	4.591	0.547	3	+ .03
		29.....	15 26	4.644	0.548	4	+ .02
	March	5.....	14 29	3.872	0.546	4	+ .01
		5.....	15 21	3.909	0.532	4	− .01
		9.....	14 31	2.141	0.560	4	+ .01
		9.....	15 29	2.181	0.522	4	− .02
		16.....	13 28	3.364	0.577	5	− .01
		16.....	14 33	3.409	0.630	4	+ .04
		17.....	13 34	4.367	0.497	5	−0.01

A discussion of the observations shows no large difference between seasons, so the normal magnitudes were formed in the usual manner by combining observations near the same phase, and the resulting normals are considered to be all of about the same weight. The observations within a single normal were weighted according to the number of sets, and ordinarily a normal comprises 19 or 20 sets taken on at least two nights. In Table III the phase and difference of magnitude are in the same sense as before, while the "rectified" magnitude refers to the deviation from a curve which will be explained later.

The results in Table III are shown in Fig. 1, and it is evident at once that this is an eclipsing system with two minima, the predicted times being shown from the last three columns of Table I. The time of periastron is from the mean of the three orbits. As there seems to be variation due to other causes, we may first consider what would influence the measures other than a variation of δ Orionis.

TABLE III

NORMAL MAGNITUDES OF δ ORIONIS

Phase	Difference of Magnitude	Rectified Magnitude	Sets	Nights	Phase	Difference of Magnitude	Rectified Magnitude	Sets	Nights
	mag.	mag.				mag.	mag.		
$0^d.099$	0.611	+0.060	19	2	$3^d.380$	0.590	+0.060	16	3
0.216	.600	+ .050	19	2	3.733	.549	+ .027	19	3
0.413	.584	+ .037	19	2	3.790	.566	+ .045	20	3
0.512	.542	− .003	20	2	3.851	.529	+ .008	19	3
0.613	.543	+ .001	22	3	3.968	.548	+ .028	19	3
0.782	.534	− .005	20	3	4.063	.533	+ .013	21	3
0.925	.543	+ .007	23	5	4.187	.520	.000	17	4
1.108	.533	− .001	19	3	4.270	.521	.000	16	3
1.217	.528	− .005	20	3	4.412	.505	− .018	21	3
1.367	.518	− .015	16	3	4.493	.480	− .045	20	2
1.489	.541	+ .008	20	3	4.620	.524	− .004	20	3
1.668	.543	+ .009	20	3	4.733	.534	+ .003	20	2
1.905	.527	− .011	19	2	4.836	.528	− .007	20	2
2.056	.554	+ .015	20	3	4.939	.551	+ .013	20	3
2.213	.540	− .002	18	3	5.025	.565	+ .025	20	2
2.321	.564	+ .021	20	3	5.167	.543	− .002	21	2
2.452	.532	− .012	16	3	5.305	.554	+ .006	19	3
2.579	.533	− .011	18	3	5.358	.549	.000	16	4
2.752	.529	− .014	20	2	5.469	.548	− .002	23	4
2.872	.541	.000	17	4	5.508	.571	+ .020	18	4
2.969	.550	+ .011	20	2	5.547	.581	+ .030	19	4
3.052	.571	+ .033	16	4	5.614	.604	+ .052	22	3
3.247	0.603	+0.070	21	2	5.684	0.631	+0.079	17	3

All of the measures have been retained except those of March 24, 1911, which was the last night of that season, twenty days later than the next preceding. For some reason the 5 sets are discordant, and are 0.05 mag. different from others at the same phase. This is the only case where observations were rejected after they were once recorded as satisfactory. Nevertheless, an inspection of Table II will show various nights when the results are systematically in error by several hundredths of a magnitude. I have been unable to find any instrumental or observing conditions which would account for these discrepancies.

We may ascribe any unexplained difficulty to a variability of the light of the single comparison star, ε Orionis. This is a spectroscopic binary of unknown period, though Professor Curtiss writes that he suspects it to be short, and nearly commensurable with some fraction of a day, like one-third or one-fourth. In order to test the results in Table II for possible variation of the comparison star, the normals in Fig. 1 were connected with straight lines in order to avoid any prejudice, and each separate observation was compared with the irregular zigzag curve found in this way. My assistant, Mr. J. D. Bond, made numerous attempts to find some period of light-variation of ε Orionis from these residuals of Table II, but without success. Any variation must be very small, as the following distribution of the residuals will show.

Residual mag.	Number	Residual mag.	Number
−0.06	1	+0.02	23
− .05	1	+ .03	13
− .04	7	+ .04	5
− .03	9	+ .05	0
− .02	32	+0.06	1
− .01	36		
.00	43		190
+0.01	19		

The distribution is nearly enough according to the law of error so that no variation of ε Orionis seems probable. The average residual is ±0.016 mag., which is small enough to call the star constant by ordinary standards.

Returning again to the discussion of the curve in Fig. 1, it is evident that there is an increase of light near periastron, due presumably to the greater interaction of the two components at the decreased distance. It is not impossible, however, that this brightening up is due to the fainter component being a variable. The view that some kind of light-variation may be caused by a resisting medium is strengthened in the present case by the stationary H and K lines in the spectrum. Also it is impossible to satisfy the observed points by drawing minima symmetrical about the predicted times of eclipses. There is indication that the times of least light are in accordance with the spectroscopic data, but in

both the primary and secondary minima, the decrease of light is more rapid than the increase, which could be attributed to the fact of each component being brighter on the front side in its orbital motion. The total effect is so small in comparison with the errors of observation, that no estimate can be made of the variation of the intensity on each apparent disk, and likewise there is no chance of determining the possible darkening at the limb of each star. The secondary minimum is apparently much longer in duration than the primary, which can be explained by assigning to the main body a larger diameter for occultation or absorption than it has for emission; in other words, it has an extensive absorbing atmosphere. We see that we are dealing with a complicated system, and any complete theory will have to wait for spectroscopic and photometric data far more accurate than anything now attainable.

We may represent the variation between minima by the first few terms of a Fourier series

$$M = a_0 + a_1 \cos \phi + b_1 \sin \phi + a_2 \cos 2\phi + b_2 \sin 2\phi ,$$

where M is the observed difference of magnitude at the phase ϕ, and the a's and b's are constants to be determined. Although this is only an empirical relation, the terms in ϕ will take care of any simple continuous variation throughout the whole period, while the terms in 2ϕ will approximate the ellipsoidal shape of the components. As only observations outside of the eclipses may be used, the limits of phase excluded were: $0^d.00$ to $0^d.55$, $2^d.90$ to $3^d.80$, and $5^d.47$ to $5^d.73$. The observation equations were formed, and then the least-squares solution gave, after combining terms,

$$M = 0^M.5368 + 0^M.0076 \sin (\phi + 43^\circ.0) + 0^M.0105 \sin (2\phi + 112^\circ.8) .$$

This equation is shown graphically by the dotted curve of Fig. 1, and the deviations from this curve give the "rectified" normals in Table III. It is seen that the effect at periastron is not closely represented by the curve, and it is probable that the effects of the various causes of light-change between minima are so intermingled that it is quite impossible to separate them. The representation of the observations by means of the series is perhaps not as good as

could be accomplished by drawing a freehand curve, but there is the advantage that any personal bias is eliminated. There is a suspicion that there is an additional minimum on each branch between the eclipses, making a total of four minima, and hence four maxima, for the light-curve; but the reality of these secondary fluctuations must remain in doubt for the present.

The rectified normals indicate the approximate variation due to eclipses, which we now consider. Let the surface brightness and the radius of the first component, and the light of the system between minima, each be taken as unity. Further let

κ = radius of second component.
λ = surface brightness of second component.
$\frac{M_0}{\pi}$ = fraction of first disk obscured at primary minimum.
L_1 = light of system at primary minimum.
L_2 = light of system at secondary minimum.

Then it easily follows that

$$\lambda = \frac{1 - L_2}{1 - L_1}. \tag{1}$$

Assuming that the primary minimum is a decrease of 0.08 mag., and the secondary 0.07 mag., then $L_1 = 0.929$ and $L_2 = 0.938$, and from (1) we have $\lambda = 0.88$. Referring to the light-curve, we see that an additional observed point might bring the secondary minimum down another hundredth of a magnitude, and then $\lambda = 1.00$. It is evident that the surface intensities are about the same, which with only one spectrum visible must mean that the second component is smaller than the primary.

It is quite hopeless to derive the radius of the companion from the form of the light-curve at minima, but we can find certain limits between which it must lie. The least possible value of κ would be when the companion is wholly projected against the larger body at minimum, or

$$\kappa^2 > \frac{M_0}{\pi} = (1 - L_1)(1 + \kappa^2\lambda).$$

Hence it follows that

$$\kappa^2 > \frac{1 - L_1}{1 - \lambda + \lambda L_1} = \frac{1 - L_1}{L_2},$$

and substituting the values of L_1 and L_2 we have $\kappa > 0.28$. The upper limit of κ as derived from the curve alone is of no value, but we have a consideration from the spectroscopic results which is more exacting. Spectrographic observers seem to agree that if the difference of light of two components of a binary exceeds about one stellar magnitude, the fainter spectrum will be blotted out. Stretching this limit a little, I assume that the companion gives not more than one-third of the light of the primary, and therefore

$$\kappa^2\lambda < 0.333, \qquad \kappa^2 < 0.0379, \qquad \kappa < 0.62.$$

For subsequent computations we adopt then

$$\lambda = 0.88,$$
$$0.28 < \kappa < 0.62.$$

While the range of κ is large, the uncertainty is no greater than in many of the well-known eclipsing systems where only one minimum has been observed.

The other elements of the system are fixed by the approximate time of duration of the eclipses, which is adopted to be 0.9 day, an avowedly rough value, since the two minima seem to differ in length. From well-known simple formulae, it is an easy matter

TABLE IV

Radius of companion, κ		0.28	0.62
Surface brightness of companion, λ		0.88	0.88
Inclination of orbit, i		72°.2	62°.6
Semi-major axis of orbit, a		2.38	2.64
Semi-major axis of orbit in km		8,320,000 km	8,920,000 km
Assumption $m_1 = 2m_2$	Radius of first component	15.1⊙	14.6⊙
	Radius of second component	4.2⊙	9.0⊙
	Mass of first component, m_1	12.6⊙	15.5⊙
	Mass of second component, m_2	6.3⊙	7.8⊙
	Density of first component	0.0036⊙	0.0050⊙
	Density of second component	0.084 ⊙	0.011 ⊙
Mean density of system		0.0054⊙	0.0061⊙

to compute the results for each limit of κ, and then to combine with the spectroscopic data. The quantities in the second column are considered the more probable. The assumption that the masses are in the ratio of 2 to 1 is quite arbitrary, but it agrees with the general rule among spectroscopic binaries, that the component

with the stronger spectrum is always the more massive. If we consider the mass of the first body to be very small compared with the second, we get the least possible value for the radius of each component, and on any assumption this comes out $5\odot$ for the larger and $1.4\odot$ for the smaller body. The mean density of the system, $0.006\odot$, may be taken as well determined, and is quite independent of the spectroscopic results. This is a somewhat lower density than is ordinarily found in a star[1] of Class B, but δ Orionis may be typical of the many eclipsing stars of small range which await discovery.

When an eclipsing variable has been observed with the spectrograph there are three quantities for which a knowledge of any two determines the third, namely, the surface brightness of one of the components compared with the sun, the ratio of the masses of the bodies, and the absolute parallax of the system. In the present case none of these quantities are known, but it may be of interest to compute what value of the parallax comes from reasonable assumptions for the others. Russell[2] estimates the surface brightness of stars of Class B to be 28 times that of the sun, which, combined with the assumed mass-ratio of 2 to 1, and the larger value of κ, gives for the parallax

$$\pi = 0''.0032.$$

Considering the three stars of the belt of Orion to be at the same general distance, and substituting their mean magnitude, 2.1, and proper motion, $\mu = 0''.0042$, in Kapteyn's formula,[3] I find

$$\pi = 0''.0019,$$

which agrees well enough with the other value. The only inference that I draw from these figures is that δ Orionis, like other stars of Class B, has a great luminosity, and its parallax is so small that direct measures are probably hopeless at present.

There is one point in connection with spectroscopic binaries which the eclipses of δ Orionis seem to settle once for all. It has been argued that some of these systems are not double, but that

[1] Shapley, *Astrophysical Journal*, **38**, 173, 1913.

[2] *Astrophysical Journal*, **40**, 417, 1914.

[3] *Groningen Publications*, No. 11, 1902.

we are dealing with only single rotating bodies. In fact, Julius[1] selected δ Orionis as an illustration of his idea that the variations of the lines of the spectrum are due to anomalous dispersion. Such considerations would have much more weight in the case of variables of the δ Cephei type, but in δ Orionis the eclipses seem to answer all argument against the existence of two bodies. Not only does the velocity-curve satisfy a Keplerian ellipse, but the times of the two minima are in agreement with the eccentric orbit, and though there are some outstanding anomalies, the main facts of the double system are established without possibility of doubt.

SUMMARY

1. The star δ Orionis has been found to be an eclipsing variable with two minima in agreement with the spectroscopic orbit. The approximate light-elements are:

$$\text{Min. I} = \text{J.D. } 2419068.20 + 5^{d}.7325 \cdot E$$
$$\text{Min. II} - \text{Min. I} = 3^{d}.20$$

2. The light between minima is also variable, there being an increase near periastron, but ellipticity of figure and other causes may also contribute to this effect. The total light-range is about 0.15 mag., of which 0.08 mag. is due to the eclipses.

3. The minima are not symmetrical about the times of greatest eclipse, and suggest that the surface brightness of each apparent disk is not uniform, but that each body is brighter on the front side in its motion in the orbit.

4. The elements of the system can be determined only within certain limits (see Table IV), but as definite results we have that the mean density of the system is 0.006 that of the sun, the larger component being at least 5 times and the smaller at least 1.4 times the solar radius.

I beg to acknowledge my indebtedness to Messrs. P. F. Whisler and H. F. Zoller for assistance in taking the observations, and to Mr. J. D. Bond for checking many of the reductions.

[1] *Astrophysical Journal*, **21**, 286, 1905.

Some years ago, I received a series of grants from the Rumford Fund of the American Academy of Arts and Sciences, amounting in all to $750.00, and the present paper is the final report on the work accomplished with the selenium photometer by the aid of these grants. I take this opportunity of returning my sincere thanks to the Rumford Committee for its timely support, and especially for the encouragement which it gave me to continue the experiments with the selenium photometer long enough to secure some kind of control over this peculiar instrument.

UNIVERSITY OF ILLINOIS OBSERVATORY
May 28, 1915

A STUDY OF THE LIGHT-CURVE OF XX CYGNI[1]

By HARLOW SHAPLEY and MARTHA BETZ SHAPLEY

XX Cygni, discovered in 1904 by Madame Ceraski,[2] is the shortest-period variable star known. It is classed as a Cepheid by Kron,[3] and the light-variation seems to have all the general characteristics peculiar to that class of variables; but unlike other Cepheids for which we have the necessary data, it is said to have a greater range visually than photographically.[4] That such an abnormality of color should be attributed to a variable already exceptional on account of its unusual period, suggests that the peculiarity may not be due to observational uncertainties. Its explanation would be that at maximum the star is redder than at minimum, the greatest intensity of the spectrum shifting toward the red with increasing light, instead of toward the violet as with all other Cepheids.[5] This would indicate that, if there is a change of spectral type with change of light, the redder spectrum occurs at maximum and not at minimum, as has been observed for RS Boötis,[6] and as is presumably true for all other Cepheids whose photographic ranges are known to exceed the visual. To determine whether the visual range of XX Cygni is really greater than the photographic, and to investigate other peculiarities of the star,[7] a study of its light-curve has been undertaken at Mount Wilson, the results of which are contained in the present communication.

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 104.

[2] *Astronomische Nachrichten*, **165**, 61, 1904.

[3] *Publikationen des Astrophysikalischen Observatoriums zu Potsdam*, **22**, Part III, 52, 1912.

[4] Parkhurst and Jordan find a photographic range of 0.63 mag. Kron's mean visual range is 0.76. But cf. Kron, *op. cit.*, p. 56.

[5] Campbell, *Stellar Motions*, p. 309, 1913.

[6] *Publications of the Astronomical Society of the Pacific*, **26**, 256, 1914.

[7] Such as irregularities in time and shape of maxima, or other features that might throw light on the cause of Cepheid variation; *Mt. Wilson Contr.*, No. 92; *Astrophysical Journal*, **40**, 448, 1914.

Because of the favorable field and the abundance of close and suitable comparison stars, XX Cygni is well adapted for accurate eye-estimates, as well as for photometric and photographic observation; and since its discovery the light-variations have been followed regularly. In 1912 E. Kron[1] published a monograph on the star, containing 2705 observations by eight different observers,[2] together with a critical discussion of the data. The period derived is $3^h14^m12^s.3547$, with the addition of a quadratic secular term. Although Kron concludes that the existence of this term is clearly demonstrated, the Mount Wilson observations show that, quantitatively at least, it is not sufficient.

On the nights of August 21 and 23, and September 18, 1914, and March 17, 1915, series of observations were made with the 60-inch reflector. On each of the first two nights the star was followed throughout an entire period. In all the observations Seed "27" and Cramer "Instantaneous Isochromatic" plates (used with a yellow color-filter) were alternated, thus giving in quick succession photographic and photo-visual magnitudes. The importance of this procedure lies in securing complete photographic and photo-visual determinations of the same epoch of maximum with the same instrument. As we shall find later, neither the shape of the curve nor the range is constant for successive periods. Therefore it is important that every photographic-photo-visual comparison should relate to the same interval of variation.

The plates obtained were as follows: August 21 and 23, 13 of each kind on each night; September 18, 5 Seed 27 and 4 isochromatic; March 17, 8 Seed 27 and 7 isochromatic, but owing to haze five of the latter were not sufficiently exposed to insure reliable measurement. In addition there are nine polar comparison plates, one of which was rejected because the cycle of comparisons with the

[1] *Op. cit.*

[2] Blažko, *Astronomische Nachrichten*, **172**, 58, 1906; Schwab, *ibid.*, **170**, 370, 1906; Parkhurst and Jordan, *Astrophysical Journal*, **23**, 84, 1906; Graff, *Astronomische Nachrichten*, **171**, 55, 1906; Luizet, *Bulletin Astronomique*, **25**, 251, 1908; Nijland, *Astronomische Nachrichten*, **188**, 149, 1911; Kron, *op. cit.*, p. 35; Hartwig, *Vierteljahrsschrift der Astronomischen Gesellschaft*, **41**, 309, 1906. The observations by Guthnick, as well as those by most of the observers named, are not published outside of Kron's monograph.

Pole is not closed and the altitude of the variable was so great that the extinction correction is large and uncertain. With the exception of the polar comparisons, each Seed 27 plate received four one-minute exposures,[1] while each isochromatic received three two-minute exposures.

The method of measurement and reduction closely follows that described by Seares in *Mt. Wilson Contr.*, No. 80.[2] Of each separate image of the variable and the comparison stars two independent measures were made, and all of the measures on each plate, corrected for distance from the center and for irregularities of the measuring scale, yielded a single mean value of the brightness of the variable.

Diaphragms were used to determine the scale of the comparison stars referred to an arbitrary zero-point; the magnitudes so obtained were reduced to the international zero by comparison with the Mount Wilson Polar Standards. Corrections for differential extinction between the variable and the Pole were made with the aid of the Potsdam tables,[3] interpolating for the altitude of Mount Wilson, and doubling the tabulated visual values to obtain the photographic corrections.

TABLE I

POLAR COMPARISON PLATES

Plate No.	Plate Kind	Date	G.M.T.	No. Exp. on Var.	No. Exp. on Pole	Length of Each Exp.	Extinction Correction	Reduction to Int. Zero
1792..	Iso.	1914 Aug. 22	$23^h\ 8^m$	2	2	2^m	−0.00 mag.	10.83 mag.
1828..	Iso.	23	23 16	2	1	2	−0.02	10.74
2325..	Iso.	1915 Mar. 15	23 43	2	2	3	+0.03	10.75
2327..	Iso.	16	0 28	2	3	2	+0.06	10.86
1791..	S. 27	1914 Aug. 22	22 52	2	2	1	+0.02	10.19
1829..	S. 27	23	23 25	2	2	1	−0.04	10.08
1890*.	S. 27	Sept. 18	15 23	2	1	1	+0.22	.....
2324..	S. 27	1915 Mar. 15	23 51	2	2	1	+0.07	10.07
2326..	S. 27	16	0 25	2	3	1	+0.11	10.13

* Rejected as a polar comparison.

Table I gives a list of the polar comparisons. The last column, giving the value of the reduction constant derived from each plate,

[1] Plate 1892 has five exposures; 1890 has two.

[2] *Astrophysical Journal*, **39**, 307, 1914.

[3] Müller, *Photometrie der Gestirne*, p. 515, 1897.

shows the satisfactory accordance of the results and indicates that that part of the probable error in the color-index which depends on the uncertainty of the zero-points is considerably less than a tenth of a magnitude.

Table II gives the adopted magnitudes of the five comparison stars as determined from seven diaphragm-plates of each kind.

TABLE II

MAGNITUDES OF COMPARISON STARS

Star	Photographic Magnitude	Av. Dev.	Photo-visual Magnitude	Av. Dev.
1.....	11.10	±0.09	10.76	±0.06
2.....	12.56	±0.10	11.33	±0.09
3.....	13.35	±0.04	.....	.....
4.....	.....	.....	11.77	±0.02
5.....	.....	.....	12.23	±0.07

On the Seed 27 plates, Nos. 1, 2, and 3 (see Fig. 3 and Table VI) were used; on the isochromatic plates, Nos. 4 and 5 were substituted for No. 3 which was too faint photo-visually to be suitable. The photographic magnitudes of Nos. 4 and 5 and the photo-visual magnitude of No. 3, which are missing from this table, were later determined, but less accurately, by a direct comparison with the Polar Standards (see Table VI).

In Table III we have the photographic and photo-visual material upon which the light-curves are based. The first column contains the number of the plate, the second the Greenwich heliocentric mean time of the middle of the exposure, the third the phase computed from Kron's elements II,[1] and the fourth the magnitude of the variable. Diaphragms were used in making the plates marked with an asterisk, the order of apertures being 60–32–60 for the isochromatic and 60–32–32–60 for the Seed 27 plates (with the exception of Plate 1892 on which the order was 60–40–32–40–60).

The data bearing on the accuracy of the light-elements are collected in Table IV. The times of maximum predicted from Kron's adopted elements (Kron II; see *op. cit.*, p. 47)[2] are given in the

[1] *Op. cit.*, p. 47.

[2] Max. = J.D. 2416563.41065, G.H.M.T. $+0^d13486522E \quad -0^d1578\times10^{-10}E^2$.

fourth column. They do not agree within allowable errors with the observed times, the greatest difference being 17 minutes. Using the

TABLE III

MOUNT WILSON OBSERVATIONS OF XX CYGNI

PHOTOGRAPHIC				PHOTO-VISUAL			
Plate	G.H.M.T.	Phase	Mag.	Plate	G.H.M.T.	Phase	Mag.
	1914 Aug. 21				1914 Aug. 21		
1752...	$20^h\ 9^m.2$	$+2^h34^m.9$	12.47	1753...	$20^h17^m.2$	$+2^h42^m.9$	12.21
1754...	27.2	52.9	12.48	1755...	34.5	3 0.2	11.92
1756*..	42.3	3 8.0	11.90	1757*..	49.7	0 1.2	11.47
1758...	57.2	0 8.7	11.54	1759...	21 4.4	15.9	11.54
1760...	21 11.9	23.4	11.68	1761...	20.0	31.5	11.70
1762*..	33.1	44.6	12.00	1763*..	40.7	52.2	11.98
1764...	48.3	59.8	12.33	1765...	55.7	1 7.2	12.03
1766...	22 3.4	1 14.9	12.23	1767...	22 10.8	22.3	12.11
1768...	18.4	29.9	12.29	1769...	26.5	38.0	12.06
1770...	34.8	46.3	12.52	1771...	42.3	53.8	12.15
1772...	49.8	2 1.3	12.45	1773...	57.9	2 9.4	12.15
1774*..	23 5.3	16.8	12.52	1775*..	23 13.1	24.6	12.17
1776...	21.2	32.7	12.48	1777	28.6	40.1	12.11
	Aug. 23				Aug. 23		
1794...	15 37.7	0 44.5	11.75	1795...	15 46.6	0 53.4	11.99
1796...	55.0	1 1.8	12.08	1797...	16 2.2	1 9.0	11.98
1798*..	16 9.9	16.7	12.25	1799*..	18.7	25.5	11.93
1800...	27.6	34.4	12.37	1801...	35.4	42.2	12.05
1802...	46.5	53.3	12.50	1803...	54.3	2 1.1	12.18
1804...	17 1.5	2 8.3	12.41	1805...	17 8.6	15.4	12.17
1806...	15.8	22.6	12.46	1807...	23.0	29.8	12.13
1808...	30.4	37.2	12.50	1809...	37.3	44.1	12.05
1810...	45.1	51.9	12.40	1811...	52.4	59.2	11.67
1812*..	59.5	3 6.3	12.08	1813*..	18 8.0	0 0.6	11.40
1814...	18 19.7	0 12.3	11.82	1815...	26.9	19.5	11.32
1816...	34.1	26.7	11.74	1817...	41.0	33.6	11.40
1818...	48.4	41.0	11.81	1819...	55.6	48.2	11.62
1829...	23 27.2	2 5.6	12.56	1828...	23 18.2	1 56.6	12.25
	Sept. 18				Sept. 18		
1890...	15 26.7	3 6.3	12.31	1891*..	15 34.0	3 13.6	11.48
1892*..	44.5	0 9.9	11.61	1893...	54.1	0 19.5	11.59
1894...	16 1.7	27.1	11.76	1895...	16 9.3	34.7	11.83
1896...	17.8	43.2	12.16	1897*..	26.9	52.3	11.86
1898*.	35.9	1 1.3	12.29				
	1915 Mar. 17				1915 Mar. 17		
2338*a*†.	22 38.9	2 46.9	12.64	2339*a*..	22 47.0	2 55.0	11.86:
b..	55.0	3 3.0	12.04	*b*..	23 1.4	3 9.4	11.76
2340*a*..	23 9.4	0 3.2	11.79	2341*a*..	15.9	0 9.7	11.35
b..	22.0	15.8	11.65	*b*..	28.5	22.3	11.56:
2342*a*..	34.9	28.7	11.70	2343*a*..	41.3	35.1	11.54:
b..	47.7	41.5	12.00	*b*..	53.8	47.6	11.67:
2344*a*..	24 0.1	53.9	12.18				
b..	16.5	1 10.3	12.20				

† The plates marked *a* and *b* each have two complete sets of exposures.

elements Kron designates as II*a*, which involve a least-squares correction to Blazko's values of the initial epoch and period but do not contain a secular term, the residuals are somewhat reduced. Although the observational data here given are not sufficient to justify a correction to Kron's elements, as far as they go, they argue against the existence of the secular term.

TABLE IV

Date	Epoch	Julian Day	Predicted Hel. Max.	Observed Hel. Max.	Obs − Kron II	Obs. − Kron II*a*
1914 Aug. 21	28202	2420366	$20^h48^m.5$	20^h57^m	+ 8	+ 3
Aug. 23	28216	2420368	18 7.4	18 24	+17	+11
Sept. 18	28408	2420394	15 34.6	15 49:	+14:	+ 8:
1915 Mar. 17	29745	2420574	23 6.2	23 21	+15	+ 8

Two of the light-curves tabulated in Table III are shown in Figs. 1 and 2. In each case we have two simultaneous records, one based on blue light, the other on light of longer wave-lengths; but both are determinations of the same maximum, so that the differences in shape, range, time of maximum, etc., which exceed the errors of observation, must be interpreted as differences of color. In shape there appears to be no great difference between the photographic and photo-visual curves on the same night, although there is a marked difference between the curves of August 21 and those of August 23. This, however, will be discussed later.

Within the errors of observation, the time of maximum is practically the same photographically and photo-visually. There is some indication, nevertheless, that the photographic maximum may come slightly later, as would be expected if there is an appreciable absorption of light in space.[1] It is in the amplitude, however, that we find the most marked difference, especially on August 21. On that date the photo-visual range is 0.72 mag. as against a photographic range of 0.97 mag. This difference in color is normal for Cepheids. The second night, on the other hand, gives a photo-visual range of 0.10 mag. greater than the photographic. The mean photographic range for the two nights is 0.86 mag., the mean

[1] Kron finds the difference vanishingly small but, if anything, in the opposite sense; *op. cit.*, p. 56.

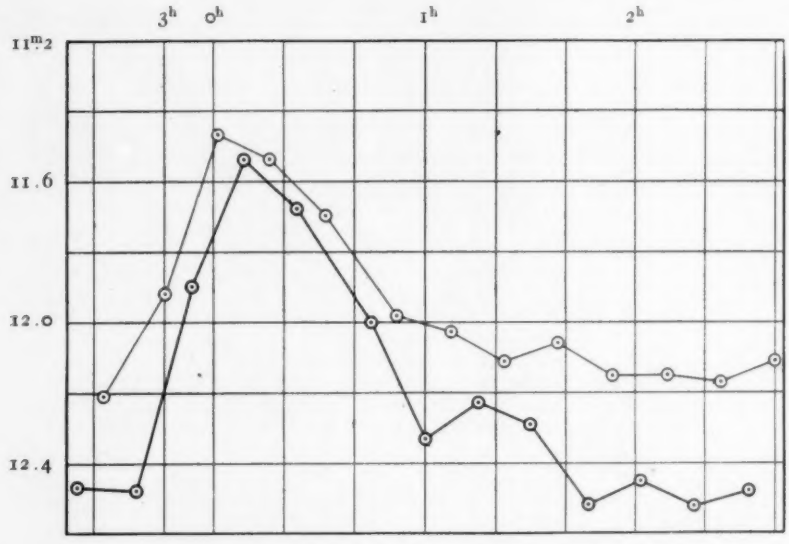


FIG. 1.—Photo-visual (above) and photographic light-curves of XX Cygni for August 21, 1914.

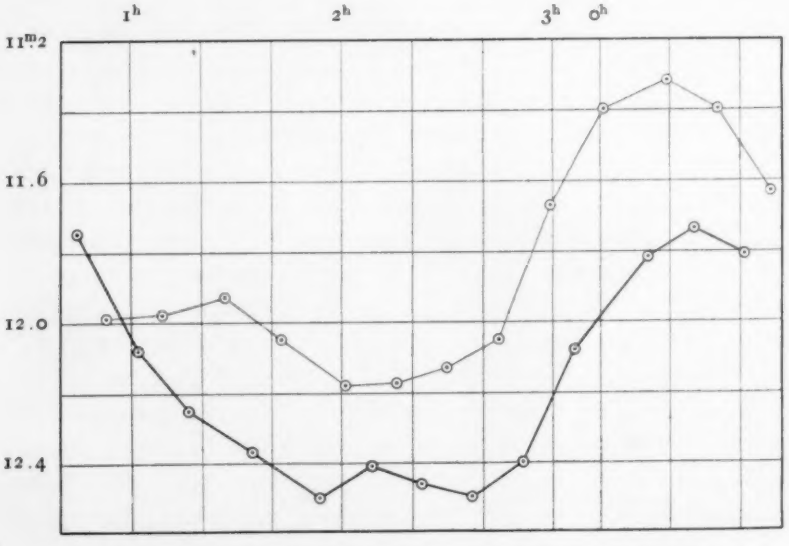


FIG. 2.—Photo-visual (above) and photographic light-curves of XX Cygni for August 23, 1914.

photo-visual is 0.78 mag.; the mean visual range found by Kron from all observers is 0.76 mag. On March 17 the photographic range is 0.99 mag., but minimum light depends on only one normal point. Thus it appears from the data now available that the photo-visual range is not greater than the photographic, and is apparently somewhat smaller.

The color and magnitude at minimum (as shown in Table V) are sensibly constant, suggesting that the irregularities occur at maximum and that the minimum is the normal condition of the

TABLE V

COLOR DATA FOR XX CYGNI

	AUGUST 21, 1914			AUGUST 23, 1914		
	Photog. Mag.	Photo-vis. Mag.	Color-Index	Photog. Mag.	Photo-vis. Mag.	Color-Index
Minimum.....	12.50	12.17	+0.33 mag.	12.49	12.17	+0.32 mag.
Maximum.....	11.53	11.45	+0.08	11.74	11.32	+0.42
Range.....	0.97	0.72	0.25	0.75	0.85	0.10

star. This is verified by the measures on the polar comparison Plates 1828 and 1829 which show a color-index at minimum of +0.31. The color-index at maximum, however, varies more than 0.3 mag.

In addition to the values tabulated above, others can be determined, but with less weight, from the two incomplete series of observations; for September 18 we find +0.15, and for March 17, +0.30. The mean for four maxima is +0.24, showing that in the mean and three times out of four the star is bluer at maximum than at minimum, and corroborating from other data the conclusion expressed above that the photographic range exceeds the photo-visual. The value of the color-index indicates an average spectrum more nearly of type F than of type A as classified at Harvard.[1]

In connection with the study of XX Cygni it was thought of interest to investigate the color of the surrounding stars. Fig. 3 shows all those within a distance of 11 minutes of arc from the variable,

[1] *Harvard Annals*, **56**, 194, 1912.

brighter than magnitude 13.7 photo-visually—the limit of visibility on our plates. Table VI contains in the first column the adopted designation of the stars, in the second Kron's designation for such of them as he has named, and in the third Kron's visual magnitude (on an extension of the Potsdam scale). In the last three columns

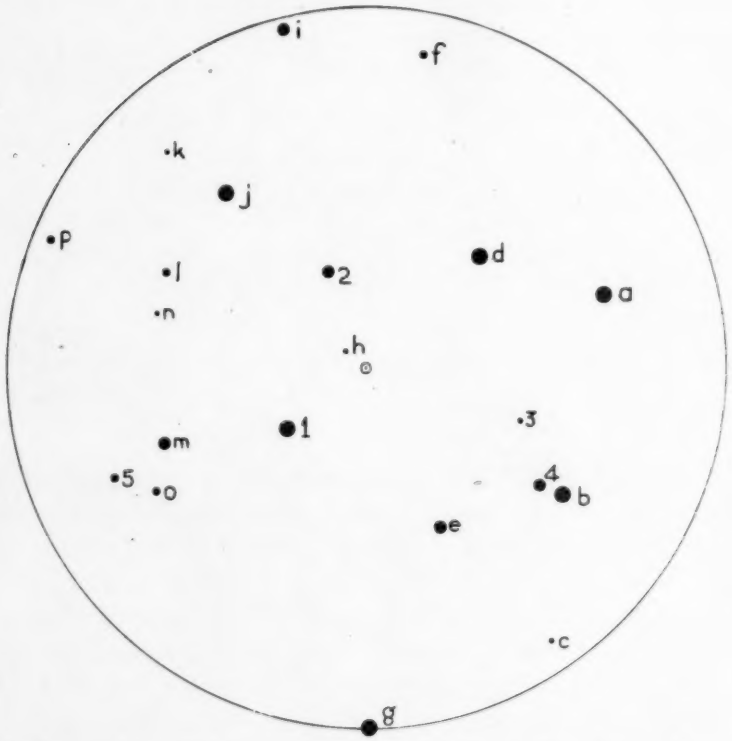


FIG. 3.—Field of XX Cygni, 20^h1^m3, $+58°40'$ (1900), giving all stars brighter than magnitude 13.7 photo-visually, within 11′ of the variable.

are the mean Mount Wilson photographic and photo-visual magnitudes, and the color-index derived from them. These magnitudes were determined from the eight polar comparison plates (Table I), which were taken in four pairs, each consisting of one isochromatic and one Seed 27 plate. Since in each case the plates compared were taken in quick succession, the color-indices are free from errors

due to possible light-variations in the stars themselves. On comparing Kron's visual results with the Mount Wilson photo-visual magnitudes, we find that the two scales are parallel throughout this range of 2.3 magnitudes, and, correcting for the systematic difference in zero-point of 0.12 mag., the average difference for the 12 stars is ±0.05 mag.

TABLE VI

COLOR-INDICES OF STARS NEAR XX CYGNI

Star	Kron		Mount Wilson		
	Designation	Visual Mag.	Photog. Mag.	Photo-vis. Mag.	Color-Index
1	11	10.56	11.10	10.76	+0.34 mag.
2	9	11.21	12.56	11.33	+1.23
3	.....	.....	13.35	13.15	+0.20
4	.....	.....	12.35	11.77	+0.58
5	5	11.94	12.38	12.23	+0.15
a	8	10.80	11.21	10.83	+0.38
b	A	10.15	11.21	10.27	+0.94
c	.....	.....	12.80	12.94	−0.14
d	B	10.29	11.52	10.39	+1.13
e	7	11.64	12.14	11.80	+0.34
f	.....	.....	12.70	12.77	−0.07
g	D	9.72	10.36:	9.83	+0.53:
h	.....	.....	14.22	13.62	+0.60
i	.....	.....	11.76	11.37	+0.39
j	E	10.33	11.36	10.40	+0.96
k	.....	.....	13.70	12.99	+0.71
l	6	11.84	13.19	11.86	+1.33
m	4	11.54	12.31	11.76	+0.55
n	.....	.....	13.76	13.29	+0.47
o	3	12.03	12.46	12.19	+0.27
p	12	.....	13.18	12.58	+0.60

The color-indices of these stars near XX Cygni were compared with those of North Polar stars within the same limits of photo-visual magnitude.[1] The results, given in Table VII, show that the average color-index of all the stars considered is less in the field of XX Cygni than near the Pole. Perhaps because the former is in the Milky Way we should expect to find these stars bluer.

It was noted above that the light-curves of XX Cygni appeared to have an entirely different shape on August 21 and 23, 1914. Such a difference from night to night is found in a much more striking degree on investigating the observations published by Kron. The

[1] *Mt. Wilson Contr.*, No. 97; *Astrophysical Journal*, 41, 206, 1915.

variations from the mean curve are certainly much larger than the errors of observation. Three pairs of curves are reproduced in Figs. 4, 5, and 6 to illustrate the extent of this irregularity of form. The first pair is taken from Guthnick's photometric measures, the second from Schwab's visual estimates, and the third from Kron's observations with the Potsdam photometer. These diagrams give examples of extreme types of maxima; all intermediate stages between them are found among the curves examined. Of the two Mount Wilson curves illustrated, that of August 21 is of the intermediate type, slightly narrower than the mean, while August 23 shows a broad round-topped curve nearing the extreme of that type. In the light of these wide variations in the form of the curves, the observed differences in range and color on different nights are much more plausible.

TABLE VII

COMPARISON OF THE COLOR OF STARS IN THE FIELD OF XX CYGNI WITH THE COLOR OF STARS AT THE NORTH POLE

LIMITS OF MAG.	NORTH POLE		FIELD OF XX CYGNI	
	No. Stars	Average Color-Index	No. Stars	Average Color-Index
10.0 to 11.0.....	7	+0.57 mag.	6	+0.71 mag.
11.0 " 12.0.....	3	+0.45	6	+0.74
12.0 " 13.0.....	14	+1.01	6	+0.25
13.0 " 14.0.....	29	+0.98	3	+0.42
10.0 " 14.0.....	53	+0.90	21	+0.55

An attempt was made to see if the change from one type of curve to another occurred at regular intervals, but from the observations published by Kron no periodicity could be established. It was noted, however, that there are no instances in which consecutive maxima showed a great difference in type (on account of the three-hour period of the star, it was on some nights observed throughout two or more successive periods). From one night to the next, on the other hand, there is often considerable change, and in the instances where observations are available for many successive nights, there is a rough indication of a periodicity of possibly a week. As all of these curves are reasonably smooth, only a part of

the difference can be attributed to errors of observation. All that can be said at present, however, is that the variation in the shape of the curve definitely exists, and that the change from one type to another appears to be gradual. The successive maxima of XX Cygni, then, are obviously not exact repetitions of the same phenomenon. Whether the minima, as well as the maxima, vary in shape, it is impossible definitely to say, for they have not been sufficiently observed; but the runs of residuals during those minima that have been observed indicate the existence of different types.

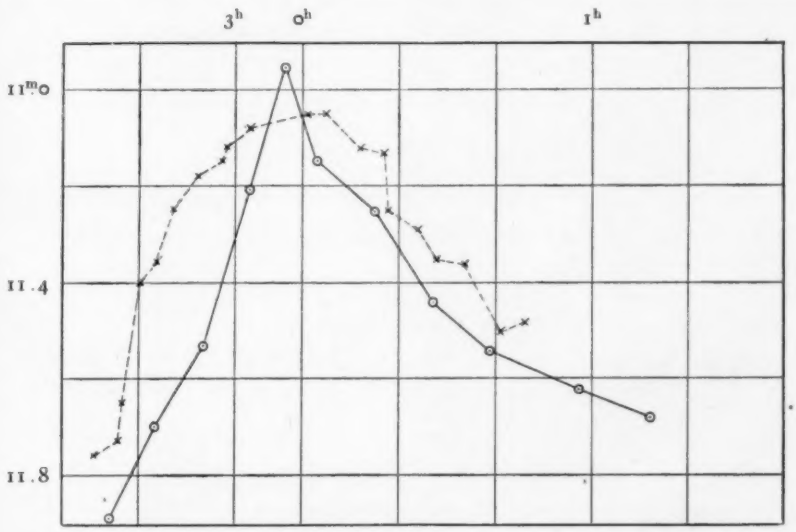


FIG. 4.—Guthnick's visual light-curves of XX Cygni for September 22, and October 5 (broken line), 1908, showing two extreme types of maximum.

To give still more evidence (if that is needed) for the reality of the different types of light-curve, Table VIII has been prepared to show that the many large residuals from the mean curves do not represent accidental errors. The deviations in each case are from the mean curve for that observer. If the variations from a mean are distributed according to the Gaussian law of error, there should be in the long run as many changes as persistences of sign. A glance at the table shows that here this is plainly not the case. These persistences of sign apparently verify from the measures of

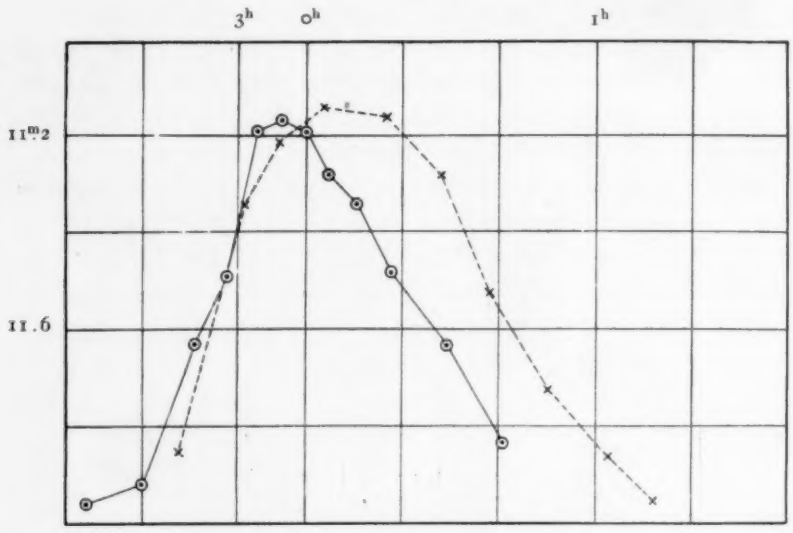


FIG. 5.—Schwab's visual light-curves of XX Cygni for January 9 (broken line) and March 13, 1905.

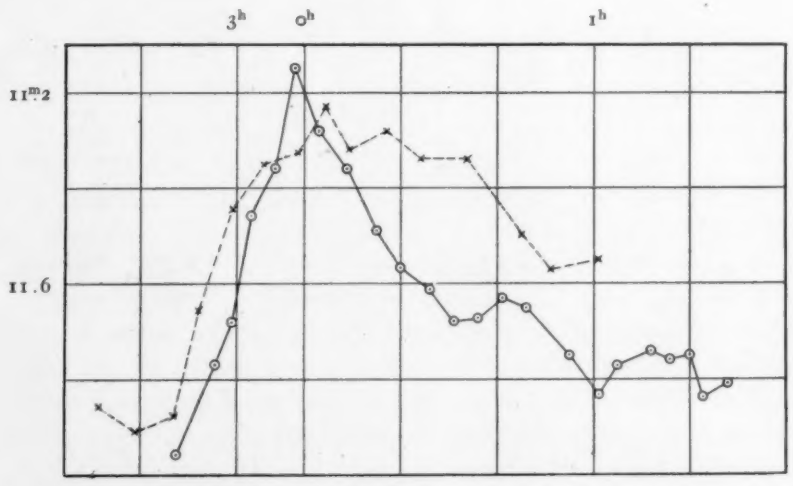


FIG. 6.—Kron's visual light-curves of XX Cygni for September 21 (broken line) and December 3, 1909.

each observer the existence of entirely different types of light-curve. They cannot be due to any appreciable extent to ordinary night error or to inconstancy of the light of comparison stars, as individual examination of each curve shows.

TABLE VIII

SYSTEMATIC RUNS OF RESIDUALS FROM MEAN CURVES

Observer	No. Persistences of Sign	No. Changes of Sign	Ratio
Blažko	431	142	3.0
Schwab	330	123	2.7
Parkhurst and Jordan	42	16	2.6
Graff	64	37	1.7
Luizet	157	50	3.1
Guthnick	239	84	2.8
Nijland	105	69	1.5
Kron	338	127	2.7
Hartwig	13	9	1.4
Total	1719	657	2.6

The conclusion must be that, whatever the cause, there is a short-period though possibly irregular change in the actual shape of the curve, and also probably a short-period oscillation in the time of maximum, though the mean period remains sensibly constant.

SUMMARY

1. To test the supposition that its visual range exceeds the photographic, and to investigate the general question of regularity in Cepheid variation, a study has been made at Mount Wilson of the light-curve of XX Cygni, the variable with the shortest known period. More than 300 exposures were made for this purpose with the 60-inch reflector.

2. It is found that, in agreement with all results for other Cepheids, the visual range does not exceed the photographic, though from the data now at hand we cannot say definitely that the photographic range is greatly in excess (Table V).

3. The stars in the field of XX Cygni within eleven minutes of arc of the variable yield an average color-index considerably less than that of North Polar stars of the same magnitudes.

4. Though a short-period oscillation in the time of maximum is suspected, the mean period of XX Cygni is sensibly constant. The secular term in Kron's elements is perhaps unnecessary; at least the light-elements which contain no secular term predict times of maximum in better accordance with the Mount Wilson observations in 1914 and 1915.

5. An examination of observations made by many observers and published by Kron shows definitely the existence of several types of maximum (Figs. 4, 5, and 6). The Mount Wilson observations confirm this (Figs. 1 and 2).

6. The maxima of XX Cygni, therefore, are not exact repetitions of the same phenomenon, but rather disturbances in the star's brightness occurring at regular intervals but varying in character.

MOUNT WILSON SOLAR OBSERVATORY
April 2, 1915

THE ELECTRIC SPARK

By W. O. SAWTELLE

PART I. THE CONTROL OF THE SPARK DISCHARGE IN AN OSCILLATORY CIRCUIT

The work on the control of the spark discharge is preliminary to a spectroscopic study of the electric spark. The plan is to reflect the image of the spark from a rotating mirror upon the slit of a spectroscope and to analyze the spectrum as it changes with the time during the oscillations. But since a single discharge does not give light enough for the purpose, it is necessary to superpose a succession of spark images upon the slit of the spectroscope with such accuracy that any particular phase of the oscillation may be brought upon the slit. Oscillations of a period of the order of a millionth of a second are used and the preliminary investigation is directed to the matter of the control or the "triggering" of the spark discharge. This problem of control of the spark has been attacked by several investigators, but the conditions imposed have been severe and success in a limited sense only has resulted.

Feddersen,[1] in his work on the electric spark, made contact in the oscillatory circuit by means of an arm attached to the axis of the rotating mirror, and with this device tried to make the discharges pass when the mirror was in the position to reflect the image of the spark upon a ground-glass plate properly placed to receive it. Later investigators, in their attempts to control the spark discharge, have employed other methods which depended upon some mechanical arrangement of commutators involving rotating arms,[2] revolving knife-edges,[3] or clockwork.[4] Although, by these agencies, the spark images fell upon the photographic plate, it was impossible to control the time variation between discharges any closer than a few thousandths of a second. This slight control,

[1] *Pogg. Ann.*, **116**, 132, 1862.

[2] Trowbridge and Sabine, *Phil. Mag.*, **30**, 323, 1890.

[3] Trowbridge, *Proc. Am. Acad.*, **27**, 115, 1891.

[4] Batelli and Magri, *Phil. Mag.* (6), **5**, 1, 1903.

however, served the purposes required of it, such as a determination of the period of the spark discharge or the verification of Thomson's formula.

For spectroscopic work, however, it is another matter, and such a degree of accuracy must be realized, if the rotating-mirror method is to be used, to permit of a time variation between successive spark discharges, not greater than the period of the oscillation whose spectrum is under investigation. This difficulty led Schuster and Hemsalech,[1] in their work on the spectrum of the electric spark, to abandon the rotating-mirror method because of the difficulties which it was impossible to eliminate at the time, although repeated efforts were made by Schuster to do so. To quote from his paper: "They [the attempts] failed because the method requires that the spark should pass when the mirror is in the same position, and no satisfactory device could be found to secure this object, without at the same time complicating the spark circuit, which it is necessary to confine as much as possible to the electrostatic capacity and spark-gap."

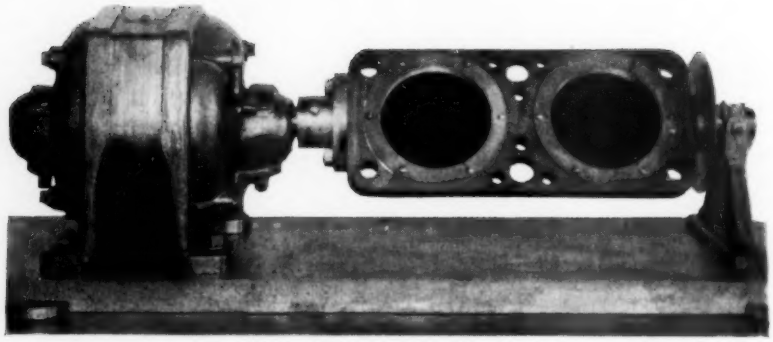
CONTROL OF THE SPARK DISCHARGE

The control of the spark discharge is obtained by means of a beam of ultra-violet light reflected from a rotating mirror, upon the negative terminal of a spark-gap in series with the principal gap, the radiations from which are to be spectroscopically studied. Ionization is thus effected, which added to that produced by the electric field is sufficient to cause the spark to pass, provided that the potential of the charging device is sufficiently high; that is to say, when the potential is building up between the terminals of the gap, the ultra-violet light, ionizing the air in the gap, "triggers" the discharge at the desired instant.

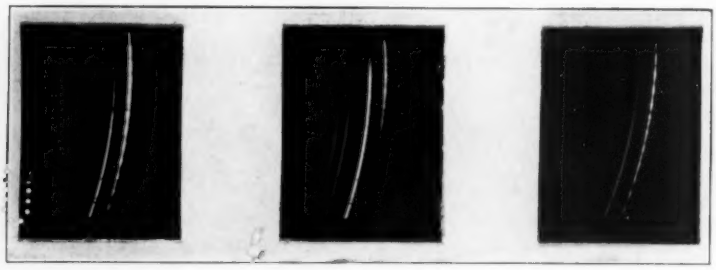
No complication of the discharge circuit results in introducing such a "triggering" device, since the second gap in series with the first or principal gap is equivalent to an increase of length of the spark in the oscillatory circuit. The method possesses none of the disadvantages of the arrangements to which reference has been made, for it allows of no uncertainty of approach of the optical

[1] Schuster and Hemsalech, *Phil. Trans.*, **193** A, 189, 1899.

PLATE II



a. Rotating Mirror System



(1) (2) (3)

b. Spectrograms of the Oscillatory Spark

One hundred spark images superposed upon the slit.

(1) Slit on initially negative terminal.
(2) Slit in middle of the gap.
(3) Slit on initially positive terminal.

trigger lever, introduces no complications in the spark circuit, prevents the jumping of different distances with different charging, eliminates the uncertainty of rubbing contacts, and permits of any length of lever arm. Since the beam of light is reflected from the rotating mirror, a double velocity may be acquired without the danger and the mechanical uncertainty which accompanies all forms of rotating arms or knife-edges.

DESCRIPTION OF APPARATUS

Rotating system.—The rotating system comprised two concave mirrors attached to the same shaft, driven by an electric motor and rotated about a horizontal axis. These mirrors were both of the same dimensions, radius of curvature 122 cm and diameter 6.2 cm, of glass with front surface silvered. They were mounted in a frame made of composition casting 31×14 cm and 2 cm thick; one end of the frame was supported by a bearing and the other was rigidly attached to the shaft of a 110-volt, one-half horse-power induction motor which made 35 revolutions per second. The whole arrangement was secured to a heavy cast-iron base (Plate II, *a*).

Oscillatory circuit.—Two spark-gaps between pointed metallic terminals in air, in series with an inductance of 3.3×10^{-5} henries (afterward increased to 8.2×10^{-5} henries) and a capacity of 0.012 microfarads, constituted the oscillatory circuit. The leads were made of heavy copper tubing, and precautions were taken to eliminate leakage. It was found that good results could be expected only when the whole circuit was carefully paraffined. The condenser was built up of thin aluminium plates (15×20 cm) between sheets of especially selected window glass, all immersed in cold pressed castor oil. The current was supplied to the circuit by a large storage battery[1] which could yield potentials up to 40,000 volts, but it was found that a potential of 20,000 volts was sufficient for the work. It is not necessary to confine one's self to a battery only, for with proper precautions a static machine may be used as a source of current.

[1] For a detailed description of this battery see: *Memoirs Am. Acad.*, **13**, No. 5, p. 185; John Trowbridge, *High Electromotive Force.*

Source of ultra-violet light.—The ultra-violet light was furnished by an iron-magnesium arc in air. The terminals were water-cooled and the distance between them was about 0.5 mm. This arc, which required only a few amperes at 500 volts, gave a very steady, well-defined spot of light, rich in ultra-violet. Investigation has shown, however, that a carbon arc with proper arrangement of slit may be substituted if a 500-volt circuit is not available, and good results obtained.

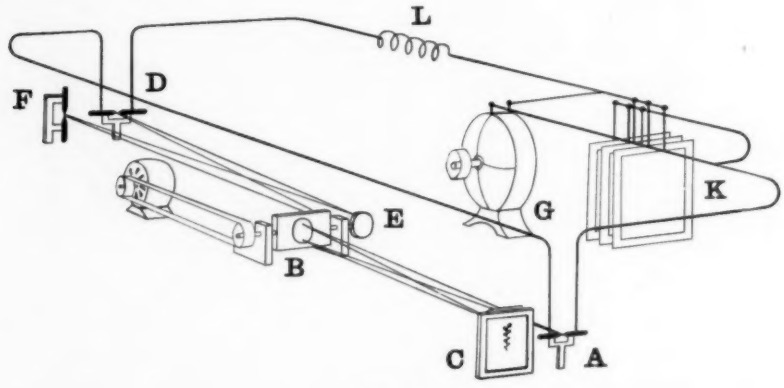


FIG. 1

Arrangement of the apparatus.—The two spark-gaps may best be designated as the "working" spark-gap (*A*) and the "trigger" spark-gap (*D*), which with the inductance (*L*) and the capacity (*K*) formed the oscillatory circuit. Early in the work the current was supplied to this circuit by a static machine with inclosed plates (*G*). This machine was later discarded because of faulty mechanical construction, and the storage battery substituted. The mirrors corresponding to the spark-gaps may be designated as the "working" mirror (*B*) and the "trigger" mirror (*E*).

The working spark at the focus of the working mirror was inclosed in a light-tight box and formed part of an optical system with the working mirror (*B*) and the photographic plate (*C*). Similarly the trigger spark, at the focus of the trigger mirror, formed part of an optical system with the trigger mirror (*D*) and the iron-magnesium arc (*F*). A schematic drawing of the arrangement is shown in Fig. 1. The spark-gaps were so protected that

both sides of the photographic plate might be uncovered and the oscillations seen through the emulsion. The final arrangement without partitions, mirror box, and motor is shown in Fig. 2.

The two spark-gaps were so adjusted with reference to the mirrors, arc, and photographic plate that when the ultra-violet light,

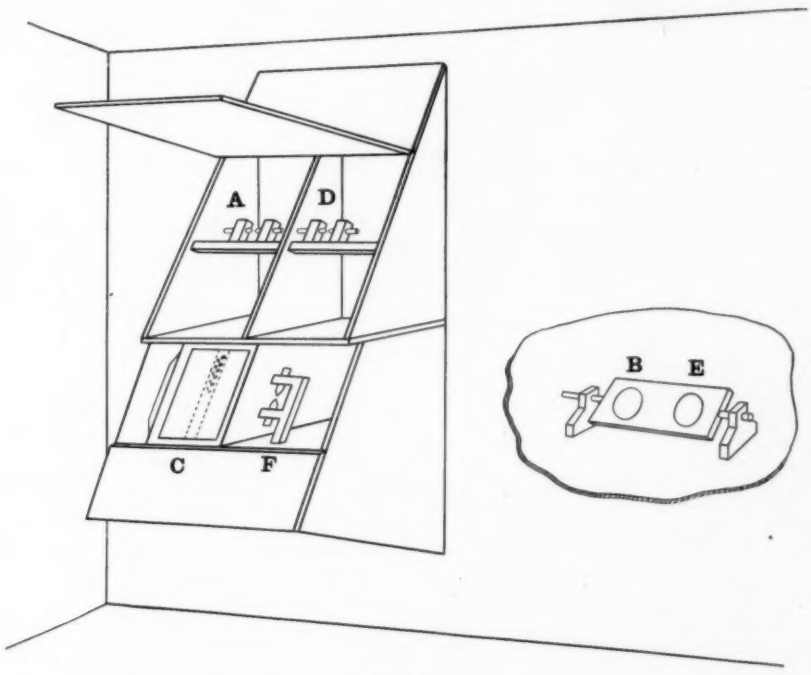


FIG. 2

after reflection from the trigger mirror, fell on the tip of the initially negative terminal of the trigger spark-gap, the reflected light from the working spark must strike a certain predetermined spot on the photographic plate. Since the two mirrors were mounted in the same rigid frame, their relative positions are not changed upon rotation, and variations in rotational speed can produce no appreciable effect upon the triggering action of the ultra-violet light. Moving the plate by hand after a spark had been recorded brought an unexposed portion into position, and upon continuing this process until all of the emulsion had been utilized, a series of several

spark images was obtained. Any deviation of the pilot sparks from the horizontal gives a direct measure of the difference in time between successive spark discharges. Since the working mirror has a radius of curvature of 1220 mm and was rotated 35 times per second, the linear distance traveled by the spark image in one second was about 500,000 mm. A millimeter's distance, therefore, on the photographic plate, measured in the direction in which the spark image was resolved, corresponds to about 2×10^{-6} seconds.

Different metals were used as electrodes in the working spark-gap; the period of the circuit was altered by varying the inductance, but in every instance the photographs obtained indicate a remarkable control of the spark discharge (Plate III). That this control may be realized, several important factors must be considered: the source of potential must be constant; leaks in the oscillatory circuit must be avoided; the terminals of the trigger spark-gap should be of copper, conical in shape, and turned to a point; the ultra-violet light should emanate from a point source and must be carefully focused upon the very tip end of the initially negative terminal of the trigger spark-gap; the optical surface of the trigger mirror must be figured with great care. It is not necessary to pay any special attention to the terminals of the trigger gap after they have once been carefully adjusted.

The reproduced photograph, with a fine thread stretched across the printing frame to serve as a horizontal co-ordinate, shows that if there exists a variation in the time interval between the spark discharges in the oscillatory circuit, as they are controlled by the ultra-violet light, it lies beyond the limits of my apparatus to show it.

It may then be stated, since a variation of a tenth of a millimeter could be detected on the negative, that this new effect of the ultra-violet in its action on the control of the spark discharge permits of a time variation between successive discharges of less than 2×10^{-7} seconds.

The terminals of the arc light were separated by a distance of less than half a millimeter and the image of the arc as it fell upon the terminal of the trigger spark-gap, after reflection from the trigger mirror, was sharp and well defined. Consequently the terminal

PLATE III

Oscillatory Spark Discharge Controlled by Means of Ultra-Violet "Triggering" Action. Cadmium Electrodes. Linear Distance Traveled by Spark Images about 500,000 mm per Second. Variation in Time between Discharges Less than 2×10^{-7} Seconds.

remains illuminated for an extremely short time, less than one-millionth of a second. This time interval is sufficiently long, however, to produce ionization and to regulate the electric field with a precision heretofore unsuspected.

PART II. THE SPECTRUM OF THE LIGHT FROM THE OSCILLATORY SPARK

It has been demonstrated that the ultra-violet control of the oscillatory spark discharge is sufficiently sensitive to cause the resolved images of the spark to fall within at least a tenth of a millimeter of the same position in space. With a slight modification of my apparatus it becomes possible to subject the light from the oscillatory spark to a spectroscopic study and at the same time to place a time co-ordinate upon the spectrogram. Quantitative measurements on the mechanism of the spark then become a matter of comparative ease, for a study of the spectrograms shows conclusively the time of appearance and decay of any particular radiation as well as its oscillatory or non-oscillatory character.

It is only necessary to mount the spectrograph with the slit vertical and in the focal plane of the rotating mirror; that is, to replace the photographic plate as used in the preliminary work. Other investigators have first formed the spectrum and then allowed it to fall upon a film attached to the periphery of a wheel which could be rapidly rotated,[1] or upon a rotating mirror so placed that if the mirror chanced to be in the proper position when the spark discharge took place, the image would be projected upon the lens of a camera. By means of this latter device C. C. Schenck[2] was enabled to observe on a ground-glass plate what I have succeeded in photographing.

A prism spectrograph, of ordinary form, designed especially for the photography of spectra from very weak sources of light, was mounted in such a way that the instrument as a whole could be rotated about the geometric axis of the rotating mirrors, while a horizontal adjustment permitted the slit, which was vertical, to be placed on either terminal of the spark-gap, or in any intermediate

[1] Schuster and Hemsalech, *Phil. Trans.*, **193** A, 189, 1899.

[2] *Astrophysical Journal*, **14**, 116, 1901.

position between the terminals. In this manner any portion of the oscillatory spark may be studied at will, while the slit, because of the arrangement, remains in the focal plane of the working mirror. Since the dispersion of the prism is small and the cone of light large, there is very little depth of focus with a noticeable curvature of the field.

Proceeding as in the preliminary work on the triggering effect, it was found that the superposition of about one hundred spark images gave a good spectrogram, but there is of course no limit to the number of images that may be made to superpose upon the slit, all falling within a tenth of a millimeter of each other.

The first metal investigated was cadmium, and with the slit upon the initially negative terminal of a spark-gap 8 mm in length, then in the middle of the gap, and finally on the initially positive terminal, the following results were obtained. On the initially negative terminal the lines of wave-length $\lambda 5379$ and $\lambda 5338$, which appear as one line because of the small dispersion, are seen to oscillate. They are followed in an extremely short time by the lines $\lambda 4800$ and $\lambda 4878$ and then in about 3×10^{-6} seconds the line $\lambda 5059$ appears. These three lines are continuous with respect to the time and they persist after the oscillations die out.

With the slit placed in the middle of the gap a spectrogram of different character was obtained. The oscillations no longer exist and the line λ 5059 radiates strongly, while the lines $\lambda\lambda$ 4800 and 4676 appear brighter than they did in the region near the terminals (Plate II, *b*, 1, 2, and 3; the horizontal lines appearing midway and near the bottom of the photographs are due to fine wires placed for reference across the slit).

These three lines $\lambda\lambda$ 4800, 4676, and 5059, continuous with respect to the time, persisting after the oscillations die out, brighter in the middle of the gap than near the terminals, and appearing in a measurable time after the passage of the initial discharge, are due to glowing metallic vapor. They are the cause, in the case of cadmium, of the luminosity which persists long after the oscillations cease. Schenck pointed out that this luminosity is probably due to metallic vapor, but by the methods which he employed he was unable to indicate this fact photographically.

This investigation was begun at the Jefferson Physical Laboratory of Harvard University, and I wish to express my thanks to Director Theodore Lyman for generously placing at my disposal the facilities of the laboratory. President Sharpless has made it possible for me to continue the work at Haverford. To the American Academy of Arts and Sciences I am deeply indebted for a liberal grant from the Rumford Fund. The problem of the spark discharge is still under investigation, and these papers are but a preliminary report.

HAVERFORD COLLEGE
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THE RADIAL VELOCITIES OF FIVE HUNDRED STARS[1]

By WALTER S. ADAMS

The program of radial velocity work for the Cassegrain spectrograph during the past few years has consisted for the most part of observations on the following classes of stars:

1. A- and B-type stars, mainly between magnitudes 5 and 6.5, a knowledge of whose motions is of particular interest as aiding in the determination of the elements of the two principal star-streams.

2. A, F, G, K, and M stars of magnitudes 5.5 to 6.5 which have very small astronomical proper motions. These may in general be considered as very distant stars of high luminosity, and are of interest as regards both their radial velocities and certain characteristics of their spectra.

3. Stars with measured parallaxes, most of which have very large proper motions. The magnitudes of these stars are chiefly between 5.5 and 8.5.[2]

In addition to these lists a number of brighter stars have been observed, for which determinations of radial velocity have been published from other observatories.

It seems desirable to make the results so far obtained available for the use of astronomers who are engaged in the discussion of stellar motions, and accordingly values are given in this communication for five hundred stars for which, with a few exceptions, three or more observations have been secured. Many other stars have been observed once or twice, and results for these will be published as soon as additional material has been obtained.

Several different optical combinations have been employed in the spectrograph during the course of these observations. The principal consideration which governs the dispersion to be used is, of course, the character of the spectrum of the star, but this has been modified in many cases by other factors. For example, the

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 105.

[2] The radial velocities of 100 of these stars were published in *Mt. Wilson Contr.*, No. 79; *Astrophysical Journal*, **39**, 341, 1914.

spectra of the small proper-motion stars have in almost all cases been photographed with low dispersion, although most of them are of the solar type, and so are well adapted for the use of high dispersion. It seemed desirable in their case to sacrifice accuracy to some extent in order to secure statistical material more rapidly, and to make it possible to institute direct comparisons between their spectra and those of the fainter stars of large proper motion and measured parallax. The different combinations used in the spectrograph may be summarized as follows. The linear scale denotes the number of Ångström units per millimeter. The 18-cm camera has been used in the case of only three of the published results.

TABLE I

No. Prisms	Camera	Linear Scale at Hγ	Stars Observed
2	38 and 46 cm	21 and 18 A	A, B, and brighter parallax stars
1	102	16	
1	46	36	Small p.m. and parallax stars
1	18	92	Parallax stars fainter than 8.5

Table II contains values for the individual stars. In view of the importance of the *Preliminary General Catalogue* of Boss for determinations of proper motion it has seemed preferable to designate the stars which occur in his catalogue by their numbers rather than to give a heterogeneous collection of names and catalogue numbers. The stars with measured parallaxes have the designations given in *Groningen Publication*, No. 24. Additional stars are indicated by the Lalande number so far as possible, the *B.D.* number being used only in a very few cases. The magnitudes are those of Harvard, with the exception of such as are given in parentheses, which are from miscellaneous sources.

The spectral classification has been made from the Mount Wilson negatives, and most of the determinations, particularly for the A and B stars, are due to Mr. Kohlschütter. Especial attention should be called to the M stars which are marked "peculiar." The peculiarity in nearly all cases consists in the combination of hydrogen lines of an intensity corresponding to that in G- and K-type stars with the bands of the M stars. Some of these stars, classified

according to the intensity of their hydrogen lines, have been discussed by Adams and Kohlschütter in a previous communication.[1]

The total proper motion μ is in most cases derived from the values given by Boss. For the parallax stars it is taken from *Groningen Publication*, No. 24. The angle λ is the angle between the star and the sun's apex. The co-ordinates used for the apex are those adopted by Kapteyn,

$$\alpha = 17^h 59^m, \quad \delta = +30°.8,$$

and the values both for μ and λ are taken from a list calculated under his direction for all of the stars given in Boss's catalogue.

The first of the two columns in Table II denoted by v contains the means of the observed radial velocities; the second the corresponding values published by other observatories. The following abbreviations are used: A, Allegheny Observatory; L, Lick Observatory; Y, Yerkes Observatory.

The final column of the table contains the values of v corrected for the solar motion. The values are given by the equation

$$v' = v + V \cos \lambda$$

in which the value 20 km has been assumed for V, the sun's motion in space.

[1] *Mt. Wilson Contr.*, No. 89; *Astrophysical Journal*, **40**, 385, 1914.

TABLE II

Star	α 1900	δ 1900	Mag.	Spec.	μ	λ	v	v	v′
Boss 5..	0h 1m2	+63° 38′	5.5	B8	0″.009	63°	− 6.8	.....	+ 2.3
18..	0 4.9	+10 35	5.4	B8	0.034	86	+13.5	.....	+14.9
41..	0 11.6	+60 59	5.8	G2	0.002	65	− 4.1	.....	+ 4.4
43..	0 11.9	+38 8	4.6	A2	0.052	74	+ 0.1	+ 6.2L	+ 5.6
56..	0 15.5	+ 7 38	5.6	Ko	0.015	89	+16.4	.....	+16.7
81..	0 22.8	+17 20	5.3	Mbp	0.117	86	+ 6.8	.....	+ 8.2
90..	0 24.9	− 4 31	6.0	K5	0.011	98	+ 5.2	.....	+ 2.4
118..	0 30.6	+53 37	5.2	B7	0.021	70	+ 2.8	.....	+ 9.6
124..	0 31.6	+14 41	5.9	B3	0.028	89	−18.3	.....	−18.0
125..	0 32.0	+34 51	5.6	Go	0.019	79	− 0.7	.....	+ 3.1
Pi. 0h130..	0 32.2	−25 19	5.7	G5	1.36	109	+15.5	+18:L	+ 9.0
Boss 131..	0 33.6	+48 48	5.7	K1	0.019	73	− 9.3	.....	− 3.5
54 Piscium ..	0 34.2	+20 43	6.1	K1	0.59	87	−33.9	.....	−32.9
Boss 138..	0 35.7	+38 55	5.4	G6	0.007	78	− 8.6	.....	− 4.4
Lal. 1198..	0 39.9	+ 1 15	8.1	K4	0.63	100	+ 6.9	.....	+ 3.4
Boss 165..	0 42.2	+ 6 12	6.2	G6	0.016	96	+14.8	.....	+12.7
169..	0 43.1	−22 16	5.3	A1	0.036	110	+19.1	.....	+12.3
Groom. 145..	0 43.2	+69 54	8.0	Ko	0.44	65	−28.0	.....	−19.6
Boss 183..	0 45.2	+50 58	6.5	F5	0.128	73	+ 1.8	.....	+ 7.6
198..	0 50.6	+26 40	5.9	a1	0.006	86	− 8.8	.....	− 7.4
209..	0 52.4	+28 27	5.6	Kop	0.017	86	0.0	.....	+ 1.4
210..	0 52.7	+13 9	6.4	G4	0.022	95	+15.7	.....	+14.0
217..	0 54.6	+ 5 57	6.3	Map	0.023	99	−14.5	.....	−17.6
Groom. 211..	0 55.6	+44 55	7.0	G4	0.105	78	−71.1	.....	−66.9
Boss 223..	0 57.3	+40 48	5.8	A6	0.024	80	+ 3.3	.....	+ 6.8
224..	0 57.3	+31 16	5.4	B9	0.039	85	+ 9.7	.....	+11.4
Lal. 1799..	0 57.2	+ 4 31	8.0	K6	0.48	100	+20.2	.....	+16.7
Boss 252..	1 3.2	+ 5 7	5.5	A4	0.326	101	+ 6.6	.....	− 3.8
261..	1 4.5	+19 7	5.6	F3	0.004	94	− 8.5	.....	− 9.9
263..	1 5.0	+63 40	5.5	B9	0.038	69	− 6.2	.....	+ 1.0
267..	1 5.4	+ 1 55	6.2	K1	0.004	103	− 2.1	.....	− 6.6
284..	1 8.8	+15 36	5.7	B2p	0.028	96	−16.1	.....	−18.2
295..	1 12.6	+ 3 5	5.4	A2	0.056	104	+ 4.6	.....	− 0.2
Lal. 2450..	1 16.9	+18 10	8.1	Go	0.57	96	0	.....	− 2
Boss 305..	1 17.5	− 0 58	6.5	Ko	0.017	107	+14.9	.....	+ 9.1
349..	1 30.5	+72 32	5.5	G5	0.008	67	− 6.7	.....	+ 1.1
355..	1 31.6	+57 28	5.7	G7	0.004	76	− 7.6	.....	+ 2.8
Lal. 3022..	1 33.9	+27 36	7.8	G7	0.50	94	+57.0	.....	+55.6
Boss 375..	1 36.0	+29 32	6.0	G4	0.013	93	+ 5.7	.....	+ 4.7
379..	1 36.3	+34 44	5.5	B9	0.053	90	+ 0.2	.....	+ 0.2
107 Piscium...	1 37.1	+19 47	5.3	G8	0.72	99	−34.2	.....	−37.3
Boss 410..	1 44.6	+21 47	5.9	G9	0.018	99	+ 3.3	.....	+ 0.2
414..	1 45.7	+10 33	5.8	F2	0.074	106	+10.6	.....	+ 5.1
420..	1 47.3	+40 14	5.6	K1	0.009	88	− 6.4	.....	− 5.7
430..	1 50.0	+36 47	6.1	K1	0.005	91	+ 7.0	.....	+ 6.7
432..	1 50.2	+36 46	5.8	Ko	0.180	91	+59.0	.....	+58.7
434..	1 50.3	+23 5	6.0	G8	0.011	100	+14.1	.....	+10.7
457..	1 55.6	+63 54	5.7	B8	0.011	74	−20.7	.....	−15.2
466..	1 57.1	+32 48	5.5	A1	0.023	94	+ 1.5	.....	+ 0.1
472..	1 58.2	+17 46	6.4	K2	0.024	104	+10.4	.....	+ 5.6
478..	2 1.7	+57 57	5.9	A4	0.009	78	−36.8	.....	−32.6
Lal. 3922..	2 2.5	− 1 5	7.5	Go	0.51	117	−40.7	.....	−49.8
Boss 488..	2 4.5	+57 10	6.4	B8	0.013	79	−36.8	.....	−33.0
493..	2 5.5	+25 28	6.2	K4	0.011	101	−18.3	.....	−22.1

TABLE II—*Continued*

Star	α 1900	δ 1900	Mag.	Spec.	μ	λ	v	z	z′
Boss 498..	2h 6m6	+66° 3′	6.2	F4	0.″003	73°	− 12.6	.....	− 6.8
508..	2 10.0	+32 54	5.3	Ao	0.035	96	− 3.2	.....	− 5.3
521..	2 12.6	+19 26	5.5	B9	0.015	106	+ 11.6	.....	+ 6.1
526..	2 13.2	+28 11	5.3	A2	0.012	100	+ 4.4	.....	+ 0.9
529..	2 14.2	+46 51	6.1	B7	0.005	88	− 0.8	.....	− 0.1
536..	2 16.6	+40 57	5.8	Fo	0.128	92	− 35.0	.....	−35.7
539..	2 16.8	− 0 4	5.6	Map	0.006	119	+ 23.3	.....	+13.6
551..	2 21.1	−12 44	4.9	B8	0.027	127	+ 0.8	.....	−11.2
572..	2 26.3	+ 1 49	5.4	K4	0.013	120	+ 27.0	.....	+17.0
581..	2 29.5	+36 52	5.9	Ko	0.010	96	− 5.8	.....	− 7.9
616..	2 37.1	+10 19	6.2	A2p	0.040	117	+ 4.7	.....	− 4.4
619..	2 37.6	+43 52	5.6	F9	0.004	92	− 3.8	.....	− 4.5
648..	2 46.0	+14 40	5.4	B5	0.045	115	+ 16.9	.....	+ 8.5
654..	2 47.4	+37 56	5.7	F2	0.10	98	+ 0.6	.....	− 2.2
660..	2 50.2	+17 56	5.9	Mc	0.018	113	+ 46.5	.....	+38.7
666..	2 51.6	− 4 7	5.1	B9	0.054	128	+ 1.7	.....	−10.6
674 N	2 53.5	+20 56	4.7	A3	0.017	112	− 7.7	.....	−15.2
674 S	2 53.5	+20 56		A3	0.017	112	− 5.3	.....	−12.8
677..	2 53.7	− 3 11	5.1	A2	0.070	128	− 4.4	.....	−16.7
W.B. 2h927..	2 55.2	+ 5 36	8.2	G8	0.68	123	+ 66.7	.....	+55.8
Boss 707..	3 1.6	− 6 29	5.6	Map	0.002	132	+17.2	.....	+ 3.8
719..	3 6.3	+26 53	5.6	Ao	0.019	109	+ 12.0	.....	+ 5.5
724..	3 8.1	+56 46	5.9	A2	0.004	85	− 14.9	.....	−13.2
W.B. 3h113..	3 9.4	+ 8 37	7.8	Ko	0.62	123	− 21.0	.....	−31.9
Boss 742..	3 11.5	+49 51	5.3	B3	0.045	91	− 0.6	.....	− 0.9
757..	3 14.7	+42 58	5.1	A1	0.058	97	− 4.6	+ 2.0L	− 7.0
767..	3 16.1	+48 51	5.4	B4	0.035	92	+ 3.4	.....	+ 2.7
768..	3 16.2	+27 15	5.6	G8	0.020	110	+ 6.7	.....	− 0.1
790..	3 22.2	+49 10	4.5	B5	0.044	93	− 1.6	.....	− 2.6
791..	3 22.4	+55 6	5.1	B9p	0.033	88	+ 1.0	+ 6.0L	+ 1.7
800..	3 24.9	−13 1	5.5	A1	0.017	140	+ 14.7	.....	− 0.6
801..	3 24.9	+11 0	5.1	B8p	0.021	124	+ 19.8	.....	+ 8.6
802..	3 25.1	+47 41	5.5	B9	0.040	94	− 2.9	.....	− 4.3
817..	3 29.4	+47 52	4.2	B7p	0.044	94	+ 0.7	.....	− 0.7
832..	3 34.5	+59 39	6.0	G8	0.002	84	− 9.9	.....	− 7.8
W.B. 3h617..	3 35.3	− 3 32	7.2	F5	0.78	137	+113.7	.....	+99.1
Boss 838..	3 35.8	+47 28	3.1	B5	0.046	96	+ 0.7	.....	− 1.4
845..	3 38.0	+36 9	5.6	A2	0.055	105	+ 21.8	.....	+16.6
849..	3 38.8	−10 48	5.7	A3	0.020	142	+ 16.2	.....	+ 0.4
B.D. 23°535..	3 41.4	+23 25	7.9	F3	.....	116	− 10.5	.....	−19.3
Boss 896..	3 48.6	+62 47	5.0	B9	0.005	83	+ 4	+ 5:L	+ 6
898..	3 48.8	+47 35	5.3	B5	0.039	96	+ 9.9	.....	+ 7.8
933..	3 58.4	+23 50	5.6	F8p	0.022	118	+ 18.3	.....	+ 8.9
956..	4 4.8	−16 39	5.3	B5	0.013	151	+ 13.3	.....	− 4.2
960..	4 5.5	− 7 11	5.6	G6	0.010	144	− 12.1	.....	−28.3
977..	4 9.6	+80 35	5.6	G7	0.020	67	− 8.6	.....	− 0.8
989..	4 11.4	+20 20	4.9	A3	0.066	123	+ 15.8	+16.8L	+ 4.9
997..	4 13.5	+20 54	5.4	B9	0.063	122	+ 13.8	.....	+ 3.2
1014..	4 16.5	+20 35	6.1	G9	0.011	123	− 8.5	.....	−19.4
1024..	4 18.7	− 3 59	5.3	Ao	0.072	144	− 0.3	.....	−16.5
1039..	4 21.3	+22 46	5.4	B5	0.019	121	+ 10.5	.....	+ 0.2
1064..	4 27.0	+64 3	5.8	A2	0.029	83	− 15.7	.....	−13.3
1069..	4 28.8	+ 5 22	5.7	A2	0.028	138	− 7.2	.....	−22.1
1084..	4 32.1	+ 0 48	5.3	B5	0.018	142	+ 22.6	.....	+ 6.8

TABLE II—*Continued*

Star	α 1900	δ 1900	Mag.	Spec.	μ	λ	v	v	v′
Boss 1088..	4h32m6	− 2°40′	5.3	A5	0.″067	146°	+ 18.2	.....	+ 1.6
1089..	4 33.4	+15 36	5.2	A2	0.074	129	+23.0	.....	+10.4
1093..	4 33.9	+48 6	5.7	Ao	0.052	99	+22.8	.....	+19.7
1097..	4 34.5	+12 0	5.3	B9	0.027	133	+ 18.1	.....	+ 4.5
1103..	4 35.8	+43 10	5.4	Ao	0.067	104	+ 5.6	.....	+ 0.8
1128..	4 42.7	+63 20	5.8	Ma	0.111	85	−35.5	.....	−33.8
1136..	4 44.0	+15 44	6.3	Ko	0.017	130	+13.5	.....	+ 0.6
1146..	4 45.7	+42 25	5.6	A1	0.013	105	− 2.4	.....	− 7.6
1163..	4 49.4	+10 0	4.7	B9	0.145	136	+17.0	.....	+ 2.9
B.D. 35°930..	4 49.7	+36 1	6.2	B3	.....	111	−11	.....	−18
Boss 1165..	4 50.1	+14 53	5.6	B9	0.025	131	+ 9	.....	− 4
1176..	4 51.8	+53 0	6.4	K3	0.012	95	− 1.8	.....	− 3.5
1182..	4 53.4	+39 15	6.0	F1	0.013	109	+ 5.7	.....	− 0.8
1183..	4 53.5	+39 30	6.9	K5	0.010	108	−23.4	.....	−29.6
W.B. 4h1189..	4 55.9	− 5 52	6.5	K9	1.25	151	+20.1	+31:L	+ 2.6
Boss 1195..	4 57.4	+58 50	5.4	B3p	0.007	89	−13.2	.....	−12.9
1221..	5 2.9	+19 44	6.6	G3	0.018	127	+ 6.0	.....	− 6.0
1234..	5 5.9	+15 55	5.4	K6	0.004	131	− 7.0	.....	−20.1
1247..	5 9.4	+ 5 2	5.8	K1	0.017	142	− 7.0	.....	−22.8
1268..	5 13.4	+33 51	5.1	A4	0.016	114	− 6.0	.....	−14.1
1281..	5 16.2	−21 20	4.7	Ao	0.020	166	+29.2	+31.5L	+ 9.8
1295..	5 18.6	− 0 15	5.5	B3	0.015	148	+22.4	.....	+ 5.4
1309..	5 20.7	+62 59	5.8	K1p	0.005	86	−18.0	.....	−16.6
1310..	5 20.7	+30 7	5.7	B9	0.019	118	+13.6	.....	+ 4.2
1318..	5 22.0	+15 47	5.5	B8	0.031	132	+13.6	.....	+ 0.2
1332..	5 26.0	+ 3 13	5.6	B3	0.009	145	+21.6	.....	+ 5.2
1334..	5 26.3	+74 59	6.4	K5	0.019	74	− 2.5	.....	+ 3.0
1348..	5 28.4	+54 22	6.0	K2	0.007	95	+ 1.4	.....	− 0.3
1354..	5 29.3	+23 58	5.1	B3	0.032	125	+23.2	.....	+11.7
Groom. 990..	5 30.4	+51 23	8.1	Ko	0.56	98	−43.8	.....	−46.6
Boss 1380..	5 32.4	+65 39	5.8	K3	0.024	83	−18.6	.....	−16.2
Pi. 5h146..	5 33.2	+53 26	6.4	Ko	0.55	96	+ 1.7	.....	− 0.4
Boss 1394..	5 34.9	+61 26	6.4	G5	0.002	88	− 3.1	.....	− 2.4
Lal. 10797..	5 39.2	+37 15	7.3	K2	0.72	112	−30.4	.....	−37.9
Boss 1424..	5 41.6	+17 41	5.3	Fo	0.010	131	+ 6.6	.....	− 6.5
1441..	5 44.5	+ 9 50	5.9	G4	0.014	139	+43.7	.....	+28.6
1444..	5 44.7	+27 56	5.6	G8	0.009	121	+ 8.1	.....	− 2.2
1453..	5 46.5	+55 41	4.8	A2	0.014	93	−15.6	−13.6L	−16.6
1479..	5 52.5	+45 56	4.6	Mbp	0.011	103	+ 0.9	+ 1.3L	− 3.6
1513..	5 59.6	+ 5 26	5.8	G4	0.007	144	+20.4	.....	+ 4.2
1514..	5 59.7	+ 4 10	5.7	G3	0.012	144	+32.7	.....	+16.5
1523..	6 1.7	− 4 11	5.4	B6p	0.007	153	+16.1	.....	− 1.7
1560..	6 8.7	+61 33	5.3	Map	0.005	87	+13.9	.....	+14.9
1568..	6 9.7	+16 10	5.2	B9	0.021	133	+29.5	.....	+15.9
1572..	6 10.1	+12 35	5.4	B9	0.017	136	+12.6	.....	− 1.8
1573..	6 10.2	+24 0	6.1	G4	0.029	125	−20.4	.....	−31.9
1575..	6 10.8	+59 3	4.5	A1	0.022	90	− 2.2	−3L, −6Y	− 2.2
1578..	6 10.9	+23 46	6.3	B6	0.014	125	+11.6	.....	+ 0.1
1599..	6 15.0	− 2 54	5.2	Ma	0.276	152	+48.3	.....	+30.6
1608..	6 18.1	+58 28	5.5	K3	0.011	91	− 4.6	.....	− 4.9
1627..	6 22.1	+58 14	6.0	G7	0.33	91	+35.7	.....	+35.4
1632..	6 22.6	+46 45	6.0	K3	0.007	103	−46.8	.....	−51.3
1643..	6 24.9	+78 5	5.9	K6	0.019	71	−13.9	.....	− 7.4

TABLE II—*Continued*

Star	α 1900	δ 1900	Mag.	Spec.	μ	λ	r	r	r′
Boss 1672..	6h29m.1	+56°56′	5.8	Ao	0".013	92°	+ 0.4	.....	− 0.3
23 Hev. Cam..	6 29.2	+79 40	5.6	A2	0.64	69	+12.0	.....	+19.2
Boss 1704..	6 35.0	+28 17	6.5	G1	0.017	121	− 3.8	.....	−14.1
1739..	6 42.3	−14 19	5.3	B8	0.012	161	+17.3	.....	− 1.6
1751..	6 44.1	+16 19	5.8	B9p	0.023	132	+12.8	.....	− 0.6
1756..	6 44.8	+13 32	5.9	G9	0.013	134	+26.8	.....	+12.9
97 Monoc.....	6 45.7	− 0 25	5.8	A5	0.20	148	−17.2	.....	−34.2
Boss 1788..	6 50.9	+10 5	6.0	B8	0.027	137	+33.0	.....	+18.4
Lal. 13427..	6 54.0	+48 32	8.2	K1	0.71	100	−22.3	.....	−25.8
Boss 1846..	7 5.6	+51 36	5.7	Map	0.019	96	−49.3	.....	−51.4
1868..	7 9.7	+28 4	5.9	K3	0.020	119	+22.2	.....	+12.5
1873..	7 10.2	+ 0 1	6.5	G4	0.019	145	− 9.6	.....	−26.0
Lal. 14146..	7 11.3	−12 53	7.3	F9	0.56	156	+57.0	.....	+38.7
Boss 1894..	7 13.5	+60 5	6.3	A7	0.011	88	+ 6.2	.....	+ 6.9
1897..	7 14.1	+45 25	5.7	A4	0.036	102	+24.6	.....	+20.4
1916..	7 16.5	+81 6	6.5	G5	0.004	68	− 1.5	.....	+ 6.0
1926..	7 18.3	+27 50	5.7	F0	0.020	118	− 5.0	.....	−14.4
1930..	7 19.4	+11 52	5.3	A2	0.028	133	+ 6.3	.....	− 7.3
1935..	7 20.1	−16 0	5.1	B5p	0.034	156	− 7.6	.....	−25.9
1956..	7 23.1	+28 19	5.0	A2	0.067	118	+42.8	+28:A	+33.4
2020..	7 36.4	+14 27	5.8	Mbp	0.015	130	−15.6	.....	−28.5
28 Hev. Cam..	7 39.8	+80 31	6.5	G6	0.49	68	− 7.8	.....	− 0.3
Boss 2054..	7 42.6	+23 23	6.2	F1	0.020	121	− 4.9	.....	−15.2
2144..	8 0.4	+22 55	6.2	Map	0.024	119	+26.7	.....	+17.0
2148..	8 2.5	+42 43	6.4	K2	0.07	101	+38.4	.....	+34.6
2150..	8 2.9	+68 46	5.5	G3	0.006	78	− 9.5	.....	− 5.3
2159..	8 4.9	−15 57	5.5	B3	0.014	148	+32.7	.....	+15.7
2178..	8 7.4	+60 41	6.4	A2	0.017	85	−16.2	.....	−14.5
2203..	8 14.3	+60 57	6.5	G8	0.008	84	− 5.4	.....	− 3.3
2220..	8 17.9	+42 20	6.2	K1p	0.011	101	+27.1	.....	+23.3
2236..	8 20.6	+45 59	6.3	G1	0.021	126	−34.3	.....	−36.7
2245..	8 21.2	+12 59	5.8	Map	0.116	124	− 7.0	.....	−18.2
2246..	8 21.5	− 3 40	5.5	A6	0.070	137	+25.5	.....	+10.9
2293..	8 31.9	+53 4	6.0	K3	0.04	90	+26.6	.....	+26.6
Lal. 16904..	8 33.1	+56 2	8.1	G3	0.44	87	+36.8	.....	+37.8
Boss 2335..	8 38.8	− 6 52	4.6	Go	0.007	136	+30.3	.....	+15.9
2338..	8 39.2	+31 4	6.1	G3	0.020	107	−12.4	.....	−18.2
2357..	8 42.2	− 1 32	5.2	B9	0.046	132	+ 1.6	.....	−11.8
2378..	8 46.5	+28 38	6.3	Mbp	0.022	108	+11.8	.....	+ 5.6
2400..	8 51.7	+15 42	5.1	A3	0.062	118	− 0.8	.....	−10.2
2407..	8 53.0	+12 15	4.1	A3	0.054	121	− 8.3	−15L, A	−18.6
2410..	8 53.5	+18 31	6.6	Mbp	0.089	115	+21.7	.....	+13.3
2413..	8 54.2	+42 11	4.1	F5	0.504	97	+23.9	+27.3L	+21.5
2449..	9 3.6	+22 27	5.2	G6	0.008	111	− 6.7	.....	−13.9
2455..	9 4.6	+22 24	6.1	G5	0.010	111	− 6.6	.....	−13.8
2461..	9 5.8	+73 22	6.0	A3	0.100	71	+ 1.9	.....	+ 8.4
81 π Cancri...	9 6.9	+15 24	6.4	G5	0.58	116	+45.9	.....	+37.1
Boss 2465..	9 7.3	+43 38	5.4	Aop	0.052	94	+26.6	+16A	+25.2
2490..	9 11.7	− 5 56	5.5	K5	0.004	129	− 7.3	.....	−19.9
2492..	9 11.8	− 8 20	5.5	B9	0.040	130	+11.0	.....	− 1.9
2584..	9 32.1	+40 41	5.2	A1	0.020	93	− 5.8	.....	− 6.8
2598..	9 35.5	+79 36	6.2	A5	0.029	65	− 6.5	.....	+ 1.9
Lal. 19022..	9 37.1	+43 10	8.2	K5	0.80	91	−12.9	.....	−13.2
Boss 2612..	9 38.3	+14 29	5.6	Map	0.014	111	+ 8.2	.....	+ 1.0

TABLE II—*Continued*

Star	α 1900	δ 1900	Mag.	Spec.	μ	λ	v	v	v′
Boss 2614..	9^h39^m4	+57° 35′	5.4	Mbp	0″.025	80°	+ 9.4	.....	+12.9
Lal. 19229..	9 43.5	+14 14	8.4	A2p	0.83	116	−23.2	.....	−30.0
Boss 2647..	9 47.0	+ 2 55	5.9	A2	0.204	116	+95.8	.....	+87.0
2650..	9 47.6	− 7 38	5.1	A1	0.076	122	+15.4	.....	+ 4.8
2701..	10 5.0	+41 9	6.5	Ko	0.017	88	+13.4	.....	+14.1
Lal. 19896..	10 8.9	+ 3 39	7.7	Go	0.47	111	−24.7	.....	−31.9
Boss 2726..	10 10.8	+65 36	5.8	A3	0.090	72	− 1.8	.....	+ 4.4
2737..	10 13.4	+69 15	5.9	A2	0.065	70	+ 3.9	.....	+10.7
2745..	10 15.2	+84 46	5.7	A2	0.130	62	+10.0	.....	+19.4
2756..	10 17.3	+34 25	5.9	A1	0.027	91	−12.7	.....	−13.0
2773..	10 21.5	+42 7	5.9	A1	0.102	86	+ 5.2	.....	+ 6.6
2787..	10 24.3	+39 26	5.9	A1	0.011	88	+ 8.2	.....	+ 8.9
2795..	10 25.7	+81 1	6.6	G6	0.016	63	−11.5	.....	− 2.4
2808..	10 27.8	+35 30	5.6	A1	0.040	88	+ 2.6	.....	+ 3.3
2813..	10 28.7	+57 36	5.2	A8	0.074	75	− 9.2	.....	− 4.0
2819..	10 30.6	+36 51	6.2	A6	0.050	87	−24.2	.....	−23.2
2822..	10 31.6	−11 42	5.7	F1	0.67	115	− 9.0	.....	−17.4
2829..	10 33.1	+32 30	4.8	Go	0.008	90	− 7.6	− 6.3L	− 7.6
2887..	10 44.4	+28 30	6.1	A7	0.021	89	+ 2.4	.....	+ 2.7
2909..	10 50.2	+25 17	4.3	A3	0.077	91	+ 6.1	.....	+ 5.8
2910..	10 50.2	+34 2	5.9	G8	0.15	86	−23.4	.....	−22.0
2915..	10 50.8	+ 6 43	6.0	Mcp	0.023	101	−12.3	.....	−16.1
2921..	10 54.0	+36 38	6.2	Ma	0.095	83	−22.7	.....	−20.3
Lal. 21258..	11 0.5	+44 2	8.9	Ma	4.46	78	+65	.....	+69
Boss 2976..	11 9.9	+23 38	4.9	Map	0.018	88	+15.2	+16.0L	+15.9
2983..	11 12.1	+ 2 34	5.4	K8	0.159	99	−57.5	.....	−60.6
2987..	11 13.7	+38 44	4.8	Ao	0.102	80	+ 5.7	.....	+ 9.2
83 Leonis Br..	11 21.7	+ 3 33	6.5	G8	0.76	96	− 2.4	.....	− 4.5
83 Leonis Ft..	11 21.7	+ 3 33	7.6	K8	0.76	96	+ 2.2	.....	+ 0.1
Boss 3045..	11 29.5	+17 21	5.8	B3	0.011	88	+17.8	.....	+18.5
3055..	11 31.6	− 9 15	5.0	B9	0.061	100	− 8.0	.....	−11.5
3063..	11 33.0	+44 11	5.6	A3	0.154	74	+ 5.6	.....	+11.1
3067..	11 33.3	+ 8 41	5.5	Mb	0.013	91	+ 1.4	.....	+ 0.9
Groom. 1822..	11 40.3	+48 14	7.9	Go	0.67	70	+23.9	.....	+30.7
Boss 3089..	11 40.7	+ 7 5	4.2	Map	0.188	90	+51.2	+51.2L	+51.2
3125..	11 50.8	+57 9	5.9	G9	0.012	66	+13.1	.....	+21.2
3137..	11 55.6	− 9 53	6.4	G6	0.47	96	0.0	.....	− 2.1
3143..	11 57.0	+43 36	4.9	A5	0.323	69	+ 8.2	.....	+15.4
3150..	11 59.2	+22 1	5.9	A5	0.044	79	+ 4.3	.....	+ 8.1
3177..	12 6.5	+82 16	6.3	K4	0.019	59	−26.0	.....	−15.7
3178..	12 6.6	+ 4 37	(7.2)	A8	0.006	86	− 6.0	.....	− 4.6
W.B. 12^h69..	12 7.4	− 2 32	7.3	G4	0.74	90	+11.3	.....	+11.3
Lal. 22908..	12 8.1	+11 24	7.5	G3	0.59	82	−30.0	.....	−27.2
Boss 3183..	12 8.3	+10 49	5.8	A8	0.096	82	+ 3.4	.....	+ 6.2
3193..	12 11.1	+41 13	5.7	K3	0.051	68	−14.4	.....	− 6.9
3206..	12 14.3	+23 35	6.1	A7	0.038	75	+ 1.2	.....	+ 6.4
3215..	12 15.4	−21 40	5.4	B8	0.092	98	−20.9	.....	−23.7
3217..	12 15.8	−13 1	5.5	K2	0.002	93	+12.5	.....	+11.5
3234..	12 20.3	+57 20	6.0	Map	0.028	62	−16.7	.....	− 7.3
3248..	12 22.8	+56 16	5.8	Ma	0.031	62	+17.6	.....	+27.0
3266..	12 26.0	+25 7	5.4	A2	0.020	71	− 0.5	.....	+ 6.0
3290..	12 31.6	− 5 17	5.9	Ao	0.040	84	− 3.6	.....	− 1.5
3294..	12 33.3	+ 2 24	6.0	Mb	0.090	81	−15.0	.....	−11.9
3309..	12 36.8	+10 47	4.8	B8	0.135	76	+ 3.5	.....	+ 8.3

TABLE II—*Continued*

Star	α 1900	δ 1900	Mag.	Spec.	μ	λ	r	v	r′
Boss 3310..	12h36m9	+ 7° 21′	5.4	Ao	0″.078	78°	+ 2.2	.....	+ 6.4
3331..	12 42.8	+ 4 7	6.7	Ma	0.013	78	+ 8.7	.....	+ 12.9
3332..	12 43.0	+63 20	5.8	A4	0.022	58	− 18.0	.....	− 7.4
3334..	12 43.2	+14 6	6.4	Ao	0.068	73	− 0.2	.....	+ 5.6
3336..	12 43.5	+67 20	5.6	G5	0.008	58	+ 9.0	.....	+ 19.6
3337..	12 43.9	+14 40	5.7	Ao	0.051	74	− 7.0	.....	− 1.5
3338..	12 44.1	+49 1	6.1	A5	0.055	60	− 2.4	.....	+ 7.6
3339..	12 44.4	+28 6	5.7	Ao	0.095	68	+ 1.4	.....	+ 8.9
3348..	12 47.2	+17 37	6.5	G9	0.023	71	− 0.4	.....	+ 6.1
3360..	12 48.8	+12 58	6.2	A3	0.067	73	− 3.8	.....	+ 2.0
3367..	12 50.6	+ 3 56	3.7	Mbp	0.479	77	− 17.4	−17.6L	− 12.9
3382..	12 56.4	+56 54	4.9	A2p	0.101	57	− 3.1	.....	+ 7.8
3406..	13 4.2	+10 33	6.0	G7	0.020	70	+ 0.1	.....	+ 6.9
3408..	13 4.5	− 9 48	6.2	K6	0.023	81	− 6.8	.....	− 3.7
3442..	13 11.5	+81 0	6.3	G5	0.008	56	− 10.0	.....	+ 1.2
3462..	13 17.1	+ 5 41	5.8	A1	0.080	70	− 11.4	.....	− 4.6
3478..	13 20.3	+24 23	5.8	A1	0.014	61	+ 1.6	.....	+ 11.3
Lal. 25012..	13 26.6	− 1 49	7.5	G6	0.94	72	− 53.9	.....	− 47.7
Boss 3499..	13 26.8	− 5 44	4.9	K5	0.112	75	− 19.1	−19.2L	− 13.9
3506..	13 29.1	+ 4 10	5.0	A2p	0.052	68	− 8.4	− 6:L	− 0.9
3534..	13 36.4	− 8 12	6.2	Ma	0.018	74	− 32.7	.....	− 27.2
3542..	13 39.1	−15 41	5.7	F8	0.009	78	+ 0.2	.....	+ 4.4
3580..	13 46.7	+35 16	6.6	A2	0.033	53	− 12.3	.....	− 0.3
3585..	13 47.4	+12 40	5.9	A1	0.038	60	− 17.1	.....	− 7.1
3589..	13 48.5	+65 13	4.8	Map	0.004	51	− 10.4	− 9.9L	+ 2.2
3629..	14 3.7	− 9 52	6.5	G8	0.016	70	− 19.6	.....	− 12.8
3653..	14 9.9	−17 44	5.5	B9	0.044	74	− 15.7	.....	− 10.2
3654..	14 9.9	+52 15	4.4	A5	0.067	46	− 15.9	−19:L	− 2.0
3663..	14 11.4	+19 23	5.9	A7	0.055	52	+ 6.3	.....	+ 18.6
Lal. 26196..	14 14.4	− 4 41	7.6	K1	0.68	64	− 13.0	.....	− 4.2
Boss 3684..	14 15.7	+39 15	6.0	Ao	0.030	46	− 12.6	.....	+ 1.3
3703..	14 21.4	+38 51	6.3	K1	0.019	45	+ 25.8	.....	+ 39.9
3706..	14 22.2	− 5 40	6.1	A1	0.098	63	− 15.6	.....	− 6.5
3734..	14 31.7	−11 53	6.0	F5	0.97	66	− 70.5	.....	− 62.4
3743..	14 35.1	+54 27	5.5	A1	0.027	43	+ 4.2	.....	+ 18.8
3756..	14 37.4	−24 34	5.6	B9	0.026	74	− 4.2	.....	+ 1.3
Lal. 27298..	14 52.4	+54 4	7.9	K0	1.08	40	− 14.4	.....	+ 0.9
A.Oe. 14320..	15 4.7	−15 54	9.2	Go	3.76	63	+290	.....	+299
Boss 3867..	15 7.5	+19 21	6.0	Mbp	0.004	40	− 34.2	.....	− 18.9
3875..	15 8.9	−17 24	6.3	B8	0.029	63	− 25.9	.....	− 16.8
3883..	15 10.3	+29 32	5.2	A2	0.078	36	− 18.8	.....	− 2.6
3885..	15 10.7	+ 0 45	5.7	A2	0.109	50	− 5.5	.....	+ 7.4
3893..	15 13.5	+67 44	5.2	F3	0.459	44	− 45.4	.....	− 31.0
3918..	15 18.6	− 0 40	6.0	A3	0.077	50	− 2.7	.....	+ 10.2
3942..	15 25.0	−16 16	5.9	Ko	0.019	60	− 1.2	.....	+ 8.8
3955..	15 29.0	− 8 51	5.1	B7p	0.029	54	− 4.3	.....	+ 7.5
3985..	15 35.1	+47 8	5.8	A8	0.162	32	− 2.3	.....	+ 14.7
4007..	15 40.4	+ 5 46	5.5	A2	0.033	41	− 7.3	.....	+ 7.8
4022..	15 45.2	+55 41	5.9	F2	0.010	34	− 1.9	.....	+ 14.7
4026..	15 45.8	+ 4 47	3.8	A6	0.136	40	− 10.6	−10.0L	+ 4.7
39 Serpentis..	15 48.5	+13 31	6.2	F8	0.56	34	+ 38.7	.....	+ 55.3
Boss 4070..	15 55.4	− 8 8	5.4	Ao	0.034	49	− 19.4	.....	− 6.3
4096..	16 2.0	−26 4	5.6	Map	0.122	63	− 21.2	.....	− 12.1
4103..	16 3.6	+ 8 48	5.9	Mbp	0.024	34	− 21.6	.....	− 5.0

TABLE II—*Continued*

Star	α 1900	δ 1900	Mag.	Spec.	μ	A	v	v	v′
Boss 4119..	16h 6m.5	− 9° 48′	5.1	A2	0″.027	48°	− 1.7	− 8.9L	+ 11.7
4120..	16 6.7	− 8 17	5.5	A2	0.041	47	− 6.4	.....	+ 7.2
4122..	16 7.0	+16 55	5.9	A2	0.014	29	− 12.6	.....	+ 4.9
4125..	16 7.4	+23 45	6.0	Mbp	0.028	26	− 24.2	.....	− 6.2
4131..	16 8.3	−11 35	5.5	K6	0.020	50	− 26.3	.....	− 13.4
4134..	16 9.1	− 3 26	3.0	Map	0.161	43	− 17.5	−19.5L	− 2.9
4137..	16 10.2	− 8 6	5.9	G1	0.53	47	+ 11.2	.....	+ 24.8
4138 Ft.	16 10.9	+34 7	6.8	F5	0.29	23	− 18.1	.....	+ 0.3
4146..	16 12.7	+29 24	5.6	A1	0.028	24	+ 6.4	.....	+ 24.7
4159..	16 15.6	+60 0	5.6	Map	0.022	34	− 35.2	.....	− 18.6
4182..	16 20.8	+14 16	4.4	A0	0.079	28	− 2.4	− 6.1L	+ 15.3
4188..	16 22.3	− 7 22	5.4	Map	0.176	44	+ 97.1	.....	+111.5
B.D. 51°2097..	16 23.0	+51 22	7.5	A1	0.109	27	− 17.6	.....	+ 0.2
Boss 4210..	16 27.7	+ 5 44	5.5	A0	0.023	32	− 26.9	.....	− 9.9
4221..	16 31.0	+61 2	5.8	A1	0.021	34	− 11.6	.....	+ 5.0
Lal. 30271..	16 32.6	+31 9	7.2	F2	0.46	18	− 8.0	.....	+ 11.0
Boss 4228..	16 33.3	+46 49	6.0	G9	0.020	23	− 16.8	.....	+ 1.6
4229..	16 33.8	+53 6	5.7	A0	0.026	28	− 7.0	.....	+ 10.7
4291..	16 47.5	+15 9	6.3	B9	0.011	23	− 22.8	.....	− 4.4
4300..	16 49.2	+31 52	5.3	A6	0.098	15	− 21.4	.....	− 2.1
4303..	16 50.3	−16 39	6.5	G8	0.089	51	− 2.2	.....	+ 10.4
4316..	16 53.4	+25 30	6.7	G5	0.009	20	+ 9.1	.....	+ 27.9
4332..	16 57.9	+33 43	5.3	A5	0.012	13	− 13.2	.....	+ 6.3
Lal. 31055..	16 59.8	− 4 54	7.9	K5	1.47	38	+ 27.5	.....	+ 43.3
Boss 4395..	17 15.2	−12 45	4.3	A1	0.036	45	+ 3.8	+ 8L	+ 17.9
4418..	17 20.0	+16 24	5.7	A8	0.044	17	+ 10.8	.....	+ 29.9
W.B. 17h322..	17 20.8	+ 2 14	7.8	K9	1.36	30	− 27.8	.....	− 10.5
Boss 4427..	17 22.5	+20 10	5.4	B6	0.016	13	− 28.2	.....	− 8.7
4438..	17 26.7	+26 11	4.5	K2	0.021	9	− 25.2	−26.1L	− 5.4
Lal. 31905..	17 26.5	+ 1 45	7.2	K4	.....	30	− 15.4	.....	+ 1.9
W.B. 17h514..	17 29.9	+ 6 4	8.6	F1	0.58	26	−148	.....	−131
Boss 4461..	17 31.7	+21 4	5.8	A4	0.028	11	− 17.5	.....	+ 2.1
4494..	17 41.9	+53 51	5.6	A0	0.043	23	+ 1.8	.....	+ 20.2
4514..	17 47.4	+48 25	6.4	B2p	0.008	17	− 16.3	.....	+ 2.8
4530..	17 51.6	+22 29	5.7	K4	0.002	8	− 43.1	.....	− 23.3
4546..	17 55.6	−17 9	6.3	K0	0.012	48	− 21.5	.....	− 8.1
4547..	17 55.6	+16 45	4.7	G8	0.012	14	− 24.4	−21.5L	− 5.0
4554..	17 56.9	+72 0	5.5	F2	0.009	41	− 5.9	.....	+ 9.2
4592..	18 4.6	+20 2	5.2	A3	0.027	11	− 16.1	.....	+ 3.5
Lal. 33439..	18 6.3	+38 27	6.7	K2	0.65	8	− 17.7	.....	+ 2.1
Boss 4601..	18 6.5	+36 27	5.9	G7	0.009	6	− 25.9	.....	− 6.0
4620..	18 12.5	+42 8	5.2	B8	0.009	12	− 20.4	.....	− 0.8
4629..	18 15.1	+24 24	5.5	K0	0.016	8	+ 0.5	.....	+ 20.3
4630..	18 15.4	−24 58	6.4	Mbp	0.011	56	+ 3.9	.....	+ 15.1
B.D. 8°3689..	18 21.4	+ 8 44	7.7	G1	0.50	23	− 22.5	.....	− 4.1
Boss 4668..	18 22.1	−17 52	6.0	B8	0.007	49	− 34.9	.....	− 21.8
4685..	18 25.6	−18 28	5.2	B8	0.035	49	− 37.8	.....	− 24.7
4686..	18 25.7	+65 30	5.0	G9	0.104	35	+ 30.0	+33.4L	+ 46.4
4702..	18 29.0	+30 29	5.4	B9	0.007	7	− 11.2	.....	+ 8.7
4707..	18 30.9	+56 58	5.1	F8	0.011	27	− 9.9	−10.4L	+ 7.9
4719..	18 32.5	− 0 24	5.8	A3	0.026	32	+ 13.3	.....	+ 30.3
4724..	18 34.6	+77 28	5.8	K0	0.006	46	+ 1.6	.....	+ 15.5
4740..	18 39.8	+ 1 57	4.9	B7	0.022	30	− 2.2	.....	+ 15.1
4748..	18 41.0	+39 34	6.7	A0	0.06	12	− 37.1	.....	− 17.5

TABLE II—*Continued*

Star		α 1900	δ 1900	Mag.	Spec.	μ	λ	v	r	v′
Boss	4750..	18^h41^m2	−10° 14′	5.8	F5	0″.005	42°	+ 9.8	.....	+ 24.7
	4758..	18 42.0	+26 33	4.9	K0	0.029	10	− 17.2	−16.6L	+ 2.5
	4763..	18 43.1	+60 57	6.2	G5	0.010	31	− 24.2	.....	− 7.1
Lal.	34986..	18 43.8	+10 39	8.1	K5	0.45	23	− 17.4	.....	+ 1.0
Boss	4772..	18 46.0	+32 42	5.8	B3	0.014	10	− 16.1	.....	+ 3.6
	4780..	18 48.0	−21 29	5.8	G3	0.012	53	− 3.8	.....	+ 8.2
	4783..	18 49.0	−15 44	5.0	B7	0.023	48	− 6.3	.....	+ 7.1
	4805..	18 51.7	+41 28	5.6	G5	0.007	15	− 8.2	.....	+ 11.1
	4816..	18 53.8	−12 59	5.4	B8p	0.025	46	− 12.5	.....	+ 1.4
	4842..	18 57.7	+50 23	5.1	B3	0.025	22	− 19.3	.....	− 0.8
	4866..	19 2.5	+24 6	5.6	A4	0.056	15	− 23.0	.....	− 3.7
	4873..	19 3.7	+35 57	5.2	B6	0.009	14	− 30.5	.....	− 11.1
	4898..	19 10.8	+14 55	5.6	K1	0.020	23	− 22.4	.....	− 4.0
	4899..	19 11.0	+21 3	5.5	A2	0.044	19	− 23.9	.....	− 5.0
	4910..	19 12.7	+49 54	6.3	G6	0.014	24	+ 6.5	.....	+ 24.8
	4912..	19 12.9	+37 57	4.5	G8	0.010	17	− 30.7	−30.3L	− 11.6
	4914..	19 13.1	+11 25	5.1	A3	0.011	26	− 16.2	.....	+ 1.8
	4917..	19 13.5	+22 51	5.2	B3	0.014	18	0.0	.....	+ 19.0
	4919..	19 13.7	+ 0 9	6.3	K1	0.009	36	− 28.0	.....	− 11.8
	4942..	19 18.8	+26 4	4.8	B8p	0.015	18	− 12.2	−12.2L	+ 6.8
	4967..	19 22.1	+19 42	6.1	K8	0.057	22	− 35.1	.....	− 16.6
	4974..	19 24.0	+ 1 45	5.7	B8	0.037	35	+ 16.8	.....	+ 33.2
	4976..	19 24.5	+24 28	4.6	K5	0.170	20	− 86.6	−85.0L	− 67.8
	4978..	19 24.8	+24 34	6.0	G6	0.012	20	− 26.4	.....	− 7.6
	5024..	19 36.2	+42 35	5.4	A0	0.032	23	− 38.8	.....	− 20.4
	5044..	19 40.5	−20 0	5.1	G9	0.165	56	+ 16.5	+23L	+ 27.7
	5063..	19 45.9	+38 27	6.2	G2	0.016	23	+ 10.6	.....	+ 29.0
	5073..	19 47.9	+18 25	6.3	B2p	0.007	28	− 10.9	.....	+ 6.8
	5088..	19 49.2	− 8 30	6.5	B7	0.029	48	− 13.4	.....	0.0
	5096..	19 51.2	+36 44	5.8	F5	0.008	24	− 24.2	.....	− 5.9
	5122..	19 54.7	+30 43	5.4	B8	0.031	25	− 0.2	.....	+ 17.9
	5125..	19 55.5	+17 15	5.6	Map	0.015	30	− 16.9	.....	+ 0.4
	5134..	19 57.8	+24 39	5.2	A3p	0.009	27	− 33.8	.....	− 16.0
	5142..	19 59.2	− 0 59	5.8	K2	0.119	43	+ 0.8	.....	+ 15.4
B.D.	36°3883..	20 3.5	+36 16	(7.1)	Map	.....	26	− 32.0	.....	− 14.0
Boss	5177..	20 7.6	+26 31	5.8	G9	0.020	28	− 22.2	.....	− 4.5
	5188..	20 10.8	+36 30	5.1	B9	0.094	28	− 13.4	−22:L	+ 4.3
	5213..	20 14.8	+34 40	5.2	F0	0.017	29	− 4.0	.....	+ 13.5
	5218..	20 15.9	+55 5	5.8	A2	0.021	34	− 2.8	.....	+ 13.8
	5220..	20 16.6	+39 5	6.1	A0	0.022	29	0.0	.....	+ 17.5
	5224..	20 17.8	+24 8	5.4	B8p	0.018	31	− 9.1	.....	+ 8.0
A.Oe.	20452..	20 17.7	−21 40	8.1	Gop	1.21	62	−179	.....	−170
Boss	5240..	20 21.6	−18 32	5.1	B8p	0.016	61	− 18.4	.....	− 8.7
	5258..	20 25.5	+36 7	5.9	A1	0.014	31	− 18.0	.....	− 0.9
	5267..	20 27.2	+36 36	6.3	F7	0.013	31	− 22.7	.....	− 5.6
	5284..	20 31.5	− 2 54	5.2	K2	0.011	50	− 10.9	.....	+ 2.0
	5296..	20 33.5	+31 10	6.4	A3	0.069	33	+ 1.8	.....	+ 18.6
	5301..	20 34.1	+20 51	4.7	A1	0.058	36	− 19.2	−15L	− 3.0
	5307..	20 34.4	+15 29	5.9	B3	0.025	39	− 2.0	.....	+ 13.5
	5316..	20 36.0	+45 19	6.5	B6	0.010	34	− 15.1	.....	+ 1.5
	5317..	20 36.6	+14 14	6.2	K2	0.012	39	− 31.1	.....	− 15.6
	5319..	20 37.0	+31 57	5.7	G7	0.018	33	− 28.0	.....	− 11.2
	5325..	20 39.1	+49 59	5.4	B3	0.006	36	− 2.6	.....	+ 13.6
	5366..	20 46.9	− 5 53	5.5	A0p	0.011	54	− 4.2	.....	+ 7.6

TABLE II—*Continued*

Star	α 1900	δ 1900	Mag.	Spec.	μ	λ	r	v	v′
Boss 5373..	20h47m8	+26°43′	4.8	G8	0″.103	37°	+ 3.3	− 0.2L	+19.3
Lal. 29208..	20 50.6	+40 19	6.5	B8p	0.025	36	−21.3	.....	− 5.1
Fed. [illegible]3638..	20 52.4	+74 23	7.8	G4	0.70	49	−30.4	.....	−17.3
Boss 5389..	20 52.5	+47 2	5.7	B8	0.006	37	−15.3	.....	+ 0.7
5397..	20 53.8	+21 56	5.6	K5	0.005	40	−27.3	.....	−12.0
5417..	20 58.7	−20 15	5.0	A2	0.060	67	+23.7	+26L	+31.5
5420..	20 59.2	+38 16	6.2	G7	0.012	37	− 2.5	.....	+13.5
W.B.20h1454..	20 59.1	+ 2 36	8.0	F3	0.56	51	− 9.3	.....	+ 3.3
Boss 5422..	20 59.6	+ 5 6	5.9	K6	0.019	50	−15.2	.....	− 2.3
5432..	21 2.3	+30 47	5.9	F5	0.010	39	− 6.0	.....	+ 9.5
B.D. 38°4362..	21 5.2	+38 19	7.9	K0	.....	39	− 8.1	.....	+ 7.4
Boss 5456..	21 9.9	−21 4	5.4	G8	0.007	69	− 6.9	.....	+ 0.3
5481..	21 16.5	+58 12	5.8	F8	0.014	43	−21.1	.....	− 6.5
5486..	21 16.8	+76 35	6.2	K2	0.020	51	+15.5	.....	+23.1
Lal. 30218..	21 18.5	+13 36	(6.6)	B6p	.....	49	− 9.0	.....	+ 4.1
Boss 5498..	21 19.5	+23 51	5.8	A6	0.124	45	−18.9	.....	− 4.8
5512..	21 21.7	+36 14	5.9	B3	0.011	42	+ 1.7	.....	+16.6
5522..	21 25.4	+23 12	4.8	Ma	0.017	46	−19.4	−17.5L	− 5.5
5542..	21 30.1	− 4 26	5.8	G5	0.021	61	− 0.3	.....	+ 9.4
5546..	21 30.7	+38 5	5.0	G8	0.148	44	−63.9	−65.5L	−51.1
5550..	21 32.4	− 0 50	6.2	A0	0.026	60	+16.9	.....	+26.9
5555..	21 33.1	+18 52	5.3	A1	0.100	49	−38.6	.....	−25.5
5558..	21 34.4	+19 49	5.8	A3	0.117	49	−13.4	.....	− 0.3
5583..	21 39.1	+40 42	5.6	K3	0.026	45	−25.9	.....	−11.8
5589..	21 39.7	− 9 33	5.3	G4	0.010	67	− 6.5	.....	+ 1.3
5590..	21 39.8	+16 53	4.3	G7	0.029	52	−25.5	−22.1L	−13.2
5599..	21 41.5	+22 29	5.4	G0	0.016	50	−10.7	.....	+ 2.2
5614..	21 44.5	+60 14	5.6	K4	0.006	47	−19.4	.....	− 5.8
5650..	21 53.8	+63 9	5.4	Map	0.012	49	−19	.....	− 6
5655..	21 56.0	+ 0 7	5.8	K1	0.006	64	+ 7.2	.....	+16.0
5657..	21 56.2	+ 7 47	5.8	K2	0.022	60	−22.8	.....	−12.8
B.D. 61°2233..	21 57.4	+61 59	6.5	B6	0.013	49	−21.0	.....	− 7.9
Boss 5664..	21 58.2	+52 24	5.7	B9	0.004	48	−22.1	.....	− 8.7
5669..	21 58.9	+44 10	5.3	A1	0.039	48	+ 0.9	.....	+14.3
Groom. 3689..	22 3.1	+52 39	8.1	G8	0.61	49	−35.6	.....	−22.5
Boss 5749..	22 11.9	− 5 53	5.8	G5	0.020	71	+ 6.9	.....	+13.4
5757..	22 15.4	+ 5 17	5.2	B7	0.019	65	−15.5	.....	− 7.1
5769..	22 18.3	− 7 42	6.1	G4	0.006	73	−13.7	.....	− 7.9
5805..	22 25.4	+57 54	(7.5)	B8	0.028	52	−25.7	.....	−13.4
5858..	22 37.1	+28 47	4.8	A3	0.039	59	+ 7.1	+ 8.7L	+17.4
5868..	22 39.6	+38 56	6.1	K4	0.016	57	−26.6	.....	−15.7
5904..	22 49.3	−16 21	3.5	A2	0.052	84	+13.4	+22L	+15.5
5920..	22 53.5	+ 8 50	6.5	F5	0.420	71	−26.9	.....	−20.4
5923..	22 54.3	−13 36	6.3	K2	0.014	84	+13.2	.....	+15.3
Lal. 45028..	22 56.6	− 4 23	7.8	K2	0.50	79	−50.7	.....	−46.9
Boss 5940..	22 58.9	+27 32	2.6	Map	0.234	64	+10.6	+ 8.4L	+19.4
5962..	23 4.5	+ 8 8	5.4	Mbp	0.004	74	+13.4	.....	+18.9
5967..	23 5.0	+ 9 17	5.4	B9	0.024	74	+11.8	.....	+17.3
5969..	23 5.5	+58 47	5.6	A3	0.015	57	−11.8	.....	− 0.9
5972..	23 5.8	+43 0	5.8	F2	0.275	60	−43.9	.....	−33.9
5973..	23 6.7	+ 8 11	5.1	B9p	0.017	75	+ 5.6	.....	+10.8
5981..	23 10.7	− 9 38	4.5	G8	0.367	85	−28.4	−26.9L	−26.7
5982..	23 10.9	+27 42	6.5	K0	0.015	67	+ 3.5	.....	+11.3
6016..	23 18.1	+59 35	5.9	G9	0.003	59	−11.2	.....	− 0.9

TABLE II—*Continued*

Star	α 1900	δ 1900	Mag.	Spec.	μ	λ	v	v	v′
A.Oe. 25685..	23h26m5	+58°37′	7.5	K1	1.″08	60	−24.7	.....	−14.7
B.D. 62°2244..	23 28.2	+62 36	7.3	G4	0.44	60	+ 8.0	.....	+18.0
Boss 6063..	23 29.7	+39 41	5.4	Aop	0.042	66	+13.2	.....	+21.3
6089..	23 38.3	+ 9 47	5.4	Map	0.007	81	−35.2	.....	−32.1
6105..	23 42.1	+56 54	5.8	Ko	0.021	62	− 5.4	.....	+ 4.0
6106..	23 42.2	+58 6	5.1	G9	0.087	62	−22.9	−20.3L	−13.4
6111..	23 44.0	+61 40	5.6	A3p	0.010	61	−55.7	.....	−46.0
6113..	23 44.3	+ 0 31	5.8	A3	0.027	86	+ 9.4	.....	+10.7
6123..	23 46.8	+ 2 22	5.8	K1	0.020	86	+ 0.9	.....	+ 2.3
6133..	23 48.0	+ 1 32	6.2	A1	0.013	87	+ 9.7	.....	+10.7
6135..	23 49.4	+56 57	5.0	F9p	0.007	63	−42.6	−42.1L	−33.5
6145..	23 52.0	+42 6	6.0	F2p	0.012	69	− 7.7	.....	− 0.5
6166..	23 56.5	+60 40	5.7	A6	0.007	63	−22.4	.....	−13.3
6176..	23 57.5	+65 33	5.8	Ko	0.018	62	−16.9	.....	− 7.5
6180..	23 59.1	+61 44	6.0	Ao	0.008	63	−18.9	.....	− 9.8

ACCURACY OF THE OBSERVATIONS

The great variety of spectral types among the stars of Table II involves a wide range in the accuracy of the determinations of radial velocity. Many of the A- and B-type stars have vague and very ill-defined lines, and for such stars the accuracy necessarily is low. In some cases as many as seven or eight determinations have been made to guard against the inclusion of possible spectroscopic binaries, and the range among the individual plates occasionally amounts to more than 10 km. On the other hand, the results for spectra having well-defined lines are usually in excellent agreement. The accompanying short table (III) shows the average of the probable errors of v for ten stars of each type selected at random from Table II.

TABLE III

Type	Quality for Measurement	Average No. Plates	Linear Scale of Plates	Probable Error
			per mm	
A and B.....	Poor	5	16 A	±1.16 km
A and B.....	Good	3	16	0.73
F.....	Good	3	36	0.98
G and K.....	Good	3	36	0.97
M.....	Good	3	36	±1.09

For the sake of uniformity it has seemed preferable to retain the fractional part of the kilometer for v wherever three observations

are available, although it can have little significance in the case of individual stars photographed with such relatively low dispersion. The fact that the linear scale of the spectra of the A and B stars is over twice that of the F, G, K, and M stars aids in counteracting the effect of the poorer quality of their lines, and so tends to make the accuracy of the determinations for all of the stars in Table II more nearly the same.

COMPARISON WITH RESULTS OF OTHER OBSERVERS

There are fifty stars in the list for which determinations of radial velocity have been published by other observers, a very large proportion being from the Lick Observatory photographs. The Lick spectrograms were in most cases taken with a dispersion of three prisms, and have a linear scale about three times that employed for most of the F, G, K, and M stars of Table II. A comparison by spectral types with the Lick Observatory results gives the values shown in Table IV.

TABLE IV

Type	No. Stars	Lick − Mount Wilson
B and A.....	21	+0.9 km
F and G.....	14	+1.6
K and M.....	12	+0.4

The star W.B. 4^h1189 has been omitted from this comparison, as it seems probable that the large difference between the two results may be due to the fact that the star has a variable velocity. The same remark may apply to one or two other stars in the list, particularly Boss 5904 and 5044. The exclusion of these stars would reduce the difference for the B and A stars from +0.9 to +0.4 km, and for the F and G stars from +1.6 to +1.1 km.

A large number of observations on the two stars α Boötis and α Tauri have been made during the period covered by the results shown in Table II. The values for these stars are given in Table V.

The evidence seems to indicate a small systematic difference in the direction of larger negative or smaller positive values for the Mount Wilson results, but it is probably no larger than may be

accounted for by the wave-lengths of the lines employed. A slight difference might arise from the fact that the iron arc has been used for comparison purposes at Mount Wilson, and that Rowland's wave-lengths have been utilized both for comparison lines and for such stellar lines as appear in the sun. The adopted values of the

TABLE V

Star	No. Plates	Mount Wilson	Lick	Yerkes
α Boötis.....	31	− 4.3 km	− 3.9 km	−4.5 km
α Tauri.....	16	+54.0	+55.1	.....

laboratory wave-lengths used for the helium lines of type B and the magnesium line λ 4481 of type A may also differ to some extent. In view of the fact that the Mount Wilson results are based mainly on comparatively low-dispersion photographs, the agreement with the Lick Observatory values must be considered as quite satisfactory.

SOME INDIVIDUAL STARS

Among the stars with exceptionally high velocities the following are of especial interest:

	v'		v'
A.Oe. 14320.....	+299 km	Lal.21258.....	+69 km
A.Oe. 20452.....	−170	Boss 2647.....	+87.0
W.B. 17^h514.....	−131		

The first of these stars has a proper motion of 3".76 and a parallax, as determined by Russell, of +0".035. Its motion in space as based on these values and its radial velocity would amount to 577 km, directed toward the vertex $\alpha = 189°$, $\delta = -70°$. At a distance of 5′ there is a second star which shares in the proper motion. The spectrum of this star is Go.

The star Lalande 21258 has a proper motion of 4".46 and a parallax of 0".20. Its absolute brightness is extremely small, its magnitude being 10.4 (sun = 5.5). In proper motion, absolute magnitude, and spectrum it resembles very strongly Lalande 21185, but the radial velocities of the two stars, though both large, are of opposite sign.

Boss 2647 is one of the very few stars of type A with a high radial velocity.

A star of exceptional interest because of the character of its spectrum is Lalande 19229. The spectral type is A2, but the line λ 4481, usually so prominent in stars of this type, is either absent or very faint. Two stars with a very similar spectrum had been found previously in the list of those having large proper motions. The data for the three stars are given in Table VI.

TABLE VI

Star	Mag.	μ	π	Spectrum
Lal. 5761.....	8.0	0".90	+0".039	A3p
Lal. 19229.....	8.4	0.83	−0.046	A2p
Lal. 28607.....	7.3	1.17	+0.029	A2p

The hydrogen lines in these stars are exceptionally narrow and well defined. Although the measured parallaxes are small, it seems probable that these stars are of comparatively low luminosity, and the suggestion may be made that the normal A-type spectrum is modified in this way in the case of stars of small absolute brightness. If such is the case, these spectral peculiarities should serve as a valuable criterion for the discovery of stars of this character. On physical grounds the absence of the spark line of magnesium at λ 4481, which is associated in the laboratory with high vapor-density and probably high temperature, and the narrowness and sharpness of the hydrogen lines, which would indicate a hydrogen atmosphere of low density, would be in harmony with this hypothesis.

Attention was called in the publication already referred to on the radial velocities of 100 stars with measured parallaxes[1] to the marked preponderance of the negative sign among the highest velocities. There seems to be no such noticeable effect in the case of the velocities given in Table II. The number of positive and negative velocities is essentially equal if $v' = 50$ km is set as a limit. Between 45 and 50 km, however, there are six negative velocities and only one with the positive sign.

[1] *Mt. Wilson Contr.*, No. 79; *Astrophysical Journal*, **39**, 341, 1914.

RADIAL VELOCITY AND PROPER MOTION

It is well known that, in general, the proper motions of the stars of type B are extremely small, those of type A considerably larger, and those of types F, G, and K larger still. The M-type stars have proper motions averaging about the same as the A stars. An observing list of stars of different types selected on the basis of apparent magnitude alone would, therefore, contain material which would not be homogeneous as regards the distances of the stars. Since large proper motions when treated statistically indicate not only small distance, but also high velocity, as is shown clearly by the values for stars of large proper motion,[1] the tendency would be in such an observing list to compare rapidly moving stars of one type with slowly moving stars of another type.

Most of the F, G, K, and M stars and some of the A stars which appear in Table II have been selected for observation because of their small proper motions. A knowledge of their radial velocities enables us to institute a comparison between the average velocities of groups of stars having these spectra with those of types B and A of the same average proper motion. In Table IV are collected the radial velocities of all of the stars in Table II, for which the proper motion is less than 0".030 annually. One K-type star and one M star with velocities exceeding 50 km have been omitted. This makes it possible to compare directly with a similar table published by Professor Campbell based on his velocities of stars of all types.[2] For the present purpose Campbell's first table based on 1034 stars is used, no constant correction K having been applied to these results. The proper motions for Campbell's stars have been taken from Boss's catalogue for the individual stars published in *Lick Observatory Bulletins*, Nos. 195, 211, and 229. Not all of these stars are used in Campbell's table, and, accordingly, the average proper motions derived are not strictly correct. In view of the large number of stars used, however, it does not seem probable that the values can be materially in error.

[1] The average value of the radial velocity (corrected for the sun's motion) of 135 stars of large proper motion, $\mu = 0".82$, as determined at Mount Wilson is 24.3 km. Stars with velocities exceeding 100 km are omitted.

[2] *Lick Observatory Bulletin*, No. 196.

The peculiar feature of this comparison is the relatively close agreement of the A and B stars and the large difference for the other stars. The question at once arises whether this may not be associated with the great increase in proper motion for Campbell's stars between type A and type F. In a recent publication by Kapteyn and Adams,[1] Professor Kapteyn has made a computation of the relationship between radial velocity and proper motion for the K stars, using as a basis Campbell's published values of radial

TABLE VII

Spectral Types	Campbell				Mount Wilson		
	No. Stars for v'	No. Stars for P.M.	Proper Motion	v' km	No. Stars	Proper Motion	v' km
O and B.....	141	224	0".031	8.99	61	0".016	8.23
A.....	133	206	0.094*	9.94	55	0.019	10.04
F.....	159	192	0.234	13.90	20	0.011	10.14
G and K.....	529	549	0.202	15.15	119	0.014	11.03†
M.....	72	78	0.074	16.55	27	0.015	12.56

*The omission of 5 stars would reduce this value to 0".079.

†The separate values of the G and K stars are G: 63, 0".013, 10.60; K: 56, 0".014, 11.53.

velocity and some of the Mount Wilson observations. The stars were selected in such a way as to eliminate so far as possible the effect of stream motion, and the components of the linear velocities were computed by aid of the mean parallaxes for stars of known proper motion and magnitude given in *Groningen Publication*, No. 8. If we assume that the results of this computation for the K stars may be applied to stars of other types, we have Table VIII connecting proper motion and radial velocity.

TABLE VIII

μ	v'	μ	v'
0".000 to 0".025.....	12.1 km	0".100 to 0".119.....	14.3 km
0.026 " 0.039.....	12.5	0.120 " 0.149.....	14.8
0.040 " 0.059.....	12.9	0.150 " 0.199.....	15.9
0.060 " 0.079.....	13.3	0.200 " 0.299.....	17.7
0.080 " 0.099.....	13.7	$\geqq$ 0.300	24.5

[1] *Communications to the National Academy of Sciences*, No. 1; *Proceedings of the National Academy of Sciences*, 1, 14, 1915.

The use of these values gives the following corrections to the radial velocities for the proper motions of the Campbell stars in Table VII in order to reduce to the average proper motion 0".031 of the O and B stars:

$$A, -1.3;\ F, -4.9;\ G \text{ and } K, -4.1;\ M, -1.0 \text{ km}.$$

Table IX shows the values with these corrections applied, and also with the reductions applied to correct for stream motion which have been calculated by Eddington.[1]

TABLE IX

Type	v' km	Campbell v' Corrected for Stream Motion	Proper Motion	v' km	Mount Wilson v' Corrected for Stream Motion	Proper Motion
O and B...	9.0	9.0 km	0".031	8.2	8.2 km	0".016
A.....	8.6	6.8	"	10.0	7.7	0.019
F.....	9.0	7.8	"	10.1	8.8	0.011
G.....	11.0	9.6	"	10.6	9.2	0.013
K.....				11.5	10.0	0.014
M.....	15.6	13.6	"	12.6	10.9	0.015

In his definitive solutions of the solar motion for the several spectral types[2] Campbell has given the average radial velocity for each type with a constant correction K applied to the velocity of each star. This constant has a value ranging from about zero for the F and G stars to over 4 km for the B stars. If we treat these values in the same way as those of Table VII we obtain Table X.

TABLE X

Type	v'	v' Corrected for Stream Motion	Proper Motion
O and B.....	6.5km	6.5km	0".031
A.....	9.6	7.4	"
F.....	9.5	8.3	"
G.....	9.1	7.9	"
K.....	13.2	11.5	"
M.....	16.1	14.0	"

The value of the constant K as used by Campbell is the average velocity v' taken according to sign for the stars of the several spectral types, and is, of course, dependent upon the value of the solar

[1] *Stellar Movements*, p. 157. [2] *Lick Observatory Bulletin*, No. 196.

motion V as derived for each type. Since the same value of V has been used for all of the Mount Wilson stars, no direct comparison is possible. It is, however, of interest to note how the value $V=$ 20 km satisfies the stars of the several types. The average velocity v' taken according to sign for the stars of Table VII is as follows:

$B, +1.26$; $A, -0.24$; $F, -0.86$; $G, +0.05$; $K, -1.18$; $M, +0.31$ km.

A change in the value of V from 20 to 19 km would reduce the residual for the B stars from $+1.26$ to $+1.06$ km. These quantities must be regarded as very moderate in size. The number of stars used is not very large, however, and hence the values might be changed materially by the inclusion of additional velocities. Thus if all of the M stars both of large and of small proper motion in Table II are included, together with one or two stars for which only a single observation is available, we obtain the following result:

No. Stars	μ	v'	v' According to Sign
43	0".058	14.54 km	−0.97 km

A similar computation for the B stars gives:

No. Stars	μ	v'	v' According to Sign
113	0".028	8.89 km	+1.62 km

The value $+1.62$ km would be reduced about 10 per cent by employing a value of the solar motion $V=19$ km.

The Mount Wilson results of Table IX seem to indicate, if interpreted directly, that among the very distant stars the change of velocity with spectral type is slight, and Campbell's results, except perhaps in the case of the M stars, point to the same conclusion when allowance has been made for the effect of the large number of relatively near stars included among his F- to M-type spectra. This would be in agreement with the hypothesis put forward by Eddington in 1911,[1] but later entirely disproved, as he

[1] *British Association Report*, 1911.

considered, by the evidence of the A stars,[1] that the relation between velocity and spectral type might be a relation between velocity and distance, the stars nearest the sun, which are mainly of types F to K, moving more rapidly than the distant stars. The evidence which Eddington regarded as conclusive in disproving this hypothesis was provided by an analysis according to proper motion of the A-type stars for which velocities had been published. No increase of radial velocity with proper motion was indicated by the results. It has already been stated in this communication that such a conclusion is by no means tenable in the case of the K stars, for which Kapteyn has found from the Lick and Mount Wilson values an increase of velocity of from 10.9 km for stars having an average proper motion of about 0".020 to 26.7 km for stars with a proper motion exceeding 0".30. The following evidence derived entirely from the Mount Wilson observations for the other types of spectra will be of interest in this connection. The effect of stream motion has not been eliminated.[2]

TABLE XI

	No. Stars	μ	v'	No. Stars	μ	v'
B.....	61	0".016	8.2 km	52	0".041	9.6 km
A.....	55	0.019	10.0	104	0.067	10.7
F.....	20	0.011	10.1	45	0.53	24.6
G.....	63	0.013	10.6	69	0.67	24.9
M.....	27	0.015	12.6	12	0.17	17.6

The agreement of these results with those obtained from the K-type stars is surprisingly close, and suggests that the empirical law connecting proper motion and radial velocity derived by Kapteyn may be applied to the other types of spectra quite as well. Only a few A-type stars of very large proper motion have been observed at Mount Wilson. Of those for which μ exceeds 0".20, two have velocities exceeding 150 km; one has a velocity of 87 km; and the average for the other six is 20 km.

The main feature of interest resulting from this comparison of proper motion and radial velocity is the low average velocity found

[1] *Stellar Movements*, p. 161.

[2] Velocities exceeding 100 km have been omitted.

for the very distant stars of types F to M. The selection of stars on the basis of small proper motion means, of course, the selection not alone of distant stars but also of those which have small intrinsic velocities as well as those whose motion is mainly in the line of sight. These factors will affect the results to some extent, especially when comparatively small numbers of stars are used. On the other hand, the direct comparison of the average velocities of groups of stars of greatly different average proper motions means a comparison in part between stars of widely different distance, and in part between slowly moving stars of one type and rapidly moving stars of another. If the rate of change of velocity with spectral type is as gradual as seems probable from these results, a very accurate knowledge of the stream motions for the different types of stars will be essential for a determination of its true value.

No attempt is made here to discuss the well-known investigation by Kapteyn,[1] in the course of which he first analyzed the relationship of radial velocities and proper motions to spectral types; nor the work of Boss,[2] in which he deduced the linear cross-motions of the stars of his catalogue according to spectral type. There can, of course, be no doubt that among the stars selected on the basis of apparent brightness those of the solar type are moving more rapidly than those of types A and B. The question which is raised is whether there exists any such marked difference for the stars of the solar type with distances comparable to those of types A and B.

The small proper-motion stars of types F to M whose motions are considered here are on the average stars of very high absolute luminosity. The possible existence of a relationship between absolute brightness and velocity has been discussed in the communication by Kapteyn and Adams, to which reference has already been made. The observational material essential to an investigation of this question would necessarily be much more extensive than that given here, and should be selected with this purpose in view. It may, however, be noted in passing that the average radial velocity of the stars of very low absolute luminosity is extraordinarily great.

[1] *Mt. Wilson Contr.*, No. 45; *Astrophysical Journal*, **31**, 258, 1910.

[2] *Astronomical Journal*, **26**, 187, Nos. 623–624, 1911.

Of the stars in the Groningen list of parallaxes with absolute magnitudes of 8 or fainter (sun = 5.5) sixteen have been observed to some extent at Mount Wilson. The average velocity of these stars (corrected for the sun's motion) is 36 km; eight have velocities exceeding 40 km, although none have been included with values higher than 100 km. It is difficult to think of these stars as other than stars of small mass, and the results for their velocities would be in agreement with the hypothesis suggested by Halm[1] that the motions of stars are a function of their masses.

I am greatly indebted to several of my colleagues at the Observatory, and particularly to Dr. Kohlschütter, for much of the observational material upon which these results are based. Several of the members of the Computing Division have assisted in measuring and reducing the photographs.

MOUNT WILSON SOLAR OBSERVATORY
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[1] *Monthly Notices*, **71**, 634, 1911.

THE INFRA-RED ARC SPECTRUM OF BARIUM

By H. M. RANDALL

This paper continues work on the infra-red arc spectrum of barium, the first results having appeared in 1911.[1] The barium arc, produced by introducing the fused chloride in the positive carbon, has always proved most unsatisfactory for bolometric measurements since these demand for the best results radiant sources of constant intensity, while the barium arc on the contrary varies greatly in intensity, goes out easily, and shifts erratically about the carbons. Work with other materials having shown that large currents were sometimes effective in producing steady arcs, their effect upon the barium arc was tried. Currents of 70 amperes or over from a 220-volt power circuit were found to give arcs relatively steady as compared with those produced by currents of 15–25 amperes. In general, except for this increased steadiness and an expected increase in brightness, the arc was of the same type as that obtained with smaller currents. At times, however, the arc becomes brilliantly white and burns very noisily though it is still steady. Under these conditions lines appear which are not obtainable with the usual type of arc characteristic of smaller currents. Most of the measurements have been made, therefore, with this type of arc. It has not yet been found possible to control these two types which change readily the one into the other; although in general a large current and a positive carbon well filled with salt and so shaped as to keep the heat in the end seems favorable for the maintenance of the noisy arc. Occasionally for considerable periods of time it may be thus maintained and settings on lines readily made. At other times it appears irregularly and observation becomes very tedious and difficult. To the use of this arc, however, must be largely ascribed the many new lines now given, as most of them are not otherwise observable.

Fig. 1 shows sufficiently the general arrangement of apparatus. The arc is mounted within a water-cooled jacket, A, which is

[1] *Annalen der Physik*, **33**, 739, 1910; *Astrophysical Journal*, **34**, 1, 1911.

provided with a forced draft for carrying the fumes from the room. The silvered mirrors M_2, M_3 have a focal length of 50 cm and are 10 cm in diameter. The grating G is mounted on the rotating table of a large Fuess spectrometer as designed by Paschen.[1] It has proved extremely satisfactory. The aluminum grating support carries a thermometer for recording the temperature of the grating. The angle between the mirrors M_2 and M_3 as seen from the grating is about 14°; the length of the slit S and the corresponding slit before the linear thermopile T is 14 mm, while the slit-width is 0.2 mm. This corresponds to a spectral region at 10,000 A, of 6 A; at 30,000 A, of 3.6 A. The entire optical system from S to T is inclosed within a blackened case.

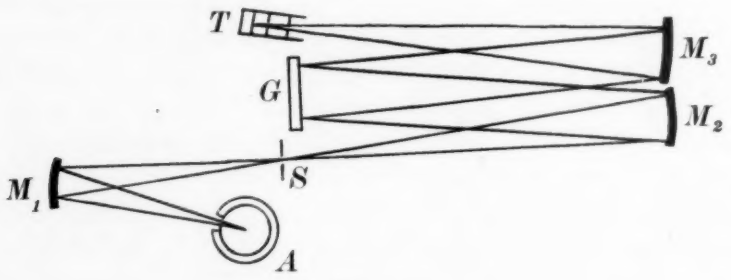

FIG. 1

Two parallel telescopes, one for each eye, enable the observer to watch simultaneously the galvanometer scale and the slit S, the latter being brought into range by suitably mounted plane mirrors. While observing, the operator, with his right hand, rotates the grating, using the slow-motion screw of the spectrometer, while with his left hand, by one set of pulleys, he can rotate the mirror M about a vertical axis and keep the image of the arc upon the slit S. By another set he can open and close the arc itself. As he is seated directly beside the arc, he is also able to replenish the arc with salt when it is required. While this complicates matters for the observer, it is not without its compensating advantages, as there is little danger of continuing observations with slit poorly illumi-

[1] Giesing, *Annalen der Physik*, **22**, 333, 1907.

nated either from want of salt in arc or from shift of arc itself. This is of particular importance during the examination of the spectrum for lines.

The galvanometer and linear thermopile are of the Paschen type,[1] the galvanometer in fact being the one previously used by the writer in Professor Paschen's laboratory in Tübingen. I wish here to express my appreciation of Professor Paschen's kindness in making possible its removal to the University of Michigan. It is a pleasure also to state my indebtedness to Professor Hussey of the department of astronomy of the University for the loan of the grating employed in the work. This is a 6-inch plane grating ruled by Dr. Anderson of Johns Hopkins University, having approximately 15,000 lines per inch. It has proved a very excellent grating for this work and has been particularly good in the neighborhood of 3 μ.

The mercury line 10,140.15[2] from a Heraeus quartz lamp was used as standard line in the calibration of the spectrometer. Energy-curves of the first-order lines to left and right were obtained by methods already described, which determined their positions accurately to within one second. The spectrometer constant given by the equation

$$\lambda = C \sin \theta$$

was 33,552.4 A, and remained constant within the fraction of an Ångström unit, as numerous calibrations at different times showed, corrections being made for small temperature changes in the grating. A complete check upon the constant so obtained resulted when the helium line 10,830.12[3] was employed, the illumination perpendicular to the capillary of the tube being used.

The entire spectrum between 32,000 A and 11,000 A was slowly passed over the slit of the linear thermopile, and spectrometer readings, sufficient to locate lines, were taken whenever the galvanometer indicated the passage of a line over the slit. This examination, first made with a slit 0.2 mm wide, was repeated with a

[1] Paschen, *Annalen der Physik*, **33**, 736, 1910; *Zeitschrift für Instrumentenkunde*, **13**, 17, 1893.

[2] Volk, Dissertation, Tübingen, 1914.

[3] Ignatieff, *Annalen der Physik*, **43**, 1135, 1914.

slit 0.5 mm wide, the second search yielding a number of weak lines and a few strong ones overlooked during the search with the narrow slit. Lines found in this manner are entirely free from any bias on the part of the observer, and only lines so found are reported here.

The measurement of the lines was made with the narrow 0.2 mm slit except where otherwise noted. The method of setting on a line has been described in detail in the previous paper and will not be repeated here. The results given in Table I are the mean of several determinations taken at different times. The intensities, based upon a slit-width of 0.2 mm, are roughly the means of the observed galvanometer throws during the settings on the lines while undergoing measurement. The wave-lengths, in Ångström units, are as measured in air according to the Rowland scale. The frequencies are the reciprocals of the wave-lengths reduced to corresponding values *in vacuo*. In general the values given may be considered correct within 2 A except in those cases especially noted.

The effect of such large currents upon the value of the wave-length cannot be stated in the case of those lines which are observable only when large currents are used, but where lines are measurable with relatively small quantities of salt and current no differences have been noticed. This is shown by the values contained in Table II.

These values were obtained at different times during a period of a year during which the spectrometer had been readjusted several times, the mirrors having been resilvered and the grating exchanged for another and then replaced.

A number of the lines given in Table I are superposed by higher orders of shorter wave-length lines; in all such cases measurements were made through suitable screens and shorter wave effects eliminated.

The carbons used gave the K lines 11,689.7, 11,771.7, 15,165.8, as impurities, the values found agreeing within 1 A of the measurements of Paschen. No other impurities were present in sufficient amount to give measurable effects. All the lines were, however, checked by using graphite rods most kindly furnished me by

TABLE I

Int.	Wave-Length	Maximum Variation from Mean	Frequency	Remarks
	9,527.3*	3.5	10,493.3	Starred values those of former paper given here for completeness
	9,610.7*	3.0	10,402.2	
	9,713.4*	1.0	10,292.3	
	9,831.7*	2.0	10,168.5	
	10,002.1*	1.0	9,995.3	
60.....	10,034.8*	1.0	9,962.6	10,035.6±2 previous value 10,034.1±1.5 present value
	10,189.1*	0.50	9,811.8	
	10,233.8*	0.5	9,768.95	
	10,272.9*	1.0	9,731.7	
	10,474.4*	1.0	9,544.5	
80.....	10,650.5*	2.00	9,386.8	10,652.4 previous single value 10,649.5±1.0 present mean value
20.....	10,692.0	1.00	9,350.3	
40.....	11,016.4	2.00	9,074.9	
10.....	11,116.0	1.0	8,993.6	Mean of two values; 0.5 mm slits
20.....	11,304.2	0.0	8,843.8	
20.....	11,608.1	0.5	8,612.4	0.5 mm slits
50.....	11,885.7	2.0	8,411.2	Possible error ±3 A
15.....	11,978.2	2.00	8,346.3	Possible error ±3 A
50.....	12,084.0	1.5	8,273.2	Not Mg line 12,083.2; strong Mg lines lacking
30.....	12,554.3	2.0	7,963.2	Possible error ±3 A
10.....	12,814.8	1.5	7,801.3	
10.....	13,057.4	0.5	7,656.4	0.5 mm slits
40.....	13,207.3	0.5	7,569.6	
40.....	13,810.5	2.0	7,238.9	Possible error ±3 A
20.....	13,956.5	2.5	7,163.2	Possible error ±3 A
40.....	14,077.9	1.5	7,101.4	
30.....	14,159.5	2.0	7,060.5	
25.....	14,211.4	1.0	7,034.7	
25.....	14,325.4	0.5	6,978.8	
40.....	15,000.4	0.5	6,664.7	
10.....	17,064.8	2.0	5,858.4	0.5 mm slits. Possible error ±3 A
5.....	17,182.5	.....	5,818.3	Doubtful, but once measurable, 0.5 mm slits
15.....	18,204.1	3.0	5,491.8	Possible error ±3 A
20.....	19,074.6	1.0	5,241.2	
25.....	19,987.9	1.5	5,001.7	
40.....	20,712.0	0.5	4,826.8	Two values also at 20,705.7
15.....	21,477.2	0.5	4,654.9	
20.....	22,220.8	1.5	4,499.1	
20.....	22,313.4	0.5	4,480.5	
30.....	23,255.3*	1.0	4,298.9	Former value 23,254.8 Present value 23,255.7
50.....	25,515.7	0.5	3,918.1	
20.....	26,221.4	1.5	3,812.7	0.5 mm slits
30.....	27,751.1	0.0	3,602.5	Mean of two values only
50.....	29,223.9*	1.0	4,321.0	Former value 29,223.4 Present value 29,224.5
35.....	29,790.6	0.5	3,355.9	
15.....	30,468.5	0.0	3,281.2	Mean of two values; 0.5 mm slits
20.....	30,686.9	0.5	3,257.9	0.5 mm slits
30.....	30,933.8	0.5	3,231.8	

Professor Saunders; the barium chloride used was that of Schuckert and showed no noticeable traces of impurities.

As regards series relations the earlier paper suggested a first term for the subordinate Series I of doublets which led to a couple of combination terms, which in fact were the principle reasons for their choice, as the frequency-differences were not very good and the wave-lengths somewhat small for this term; the selection was called a doubtful one. Shortly after its publication Professor Saunders wrote calling attention to the fact that the lines 10,035.6

TABLE II

CURRENT 70–80 AMPERES WITH LARGE QUANTITIES OF SALT IN CARBON. 0.5 MM SLITS

INTENSITIES		
50 mm	70 mm	60 mm
λ 30,934.2	29,791.2	29,225.6
λ 30,933.5	29,790.7	29,223.4

CURRENT 30 AMPERES WITH SMALL QUANTITIES OF SALT IN CARBON. 0.2 MM SLITS

INTENSITIES		
15 mm	20 mm	30 mm
λ 30,933.7	29,790.1	29,224.7

and 10,652.4 have a frequency-difference of 575 which characterizes the narrow pairs found in the ultra-violet by Lyman and that if there were a line at 12,085 the three could make a first term for the subordinate Series I of doublets and would strengthen the relation apparently existing between the first terms of the wide-pair series and the narrow-pair series, already fairly well established in case of Ca and Sr. An examination of the original observations showed no trace of any such line; neither did a search for it under approximately the same experimental conditions as obtained in the original work. When, however, the spectrometer readings roughly locating the lines found during the first search with large arc currents

through the spectral region 32,000–11,000 A were worked out, a line at 12,085 appeared among the rest. It is a line not obtainable with small current and quiet arc, though always present with the other type. The similarities which this triplet and the narrow pair series show to the corresponding terms of calcium and strontium constitute their principal claim to being considered the corresponding quantities for barium. While as far as frequency-differences are concerned, this group leaves little to be desired, its wave-lengths are shorter than might be expected from analogy to the corresponding ones of calcium and strontium. It is to be noted also that the line 12,084.0 does not appear under conditions which readily produce the other two, i.e., the quiet arc. A group better meeting the requirements of this point of view does not, however, appear in the present data, nor was such a group found among the results of a preliminary survey of the region 3 μ to 10 μ with a coarser grating.

It should be added that this relationship has been recently challenged by Popow,[1] who suggests the group 6498.9, 6143.6, 5855.5 (λ vac.) for the first term of the subordinate Series I of doublets and the group 2348.4, 2336.0, 2305.0 (λ vac.) as a term of the corresponding ultra-violet series. The question must remain open awaiting further experimental data.

The group of lines, only two of which were previously found,

$2\,p^i$	28,472.0		29,350.4		29,720.7[2]	
λ	22,313.4		27,751.1		30,933.8	
γ	4,480.4	877.9	3,602.5	370.7	3,231.8	
$3\,d''$	32,952.4		32,952.9		32,952.5	Mean 32,952.6
	181.5		181.5			
λ	23,255.3		29,223.9			
γ	4,298.9	877.9	3,421.0			
$3\,d'$	32,770.9		32,771.4			32,771.2
	380.8					
λ	25,515.7					
γ	3,918.1					
$3d$	32,390.1					32,390.1

[1] *Annalen der Physik*, **45**, 171, 1914.

[2] Ritz, *Astrophysical Journal*, **29**, 243, 1909.

is characterized by the frequency differences 878, 371, typical of the main subordinate Series I of triplets, while the differences 381, 181 are typical of the series of narrow triplets. It may be regarded accordingly as the first term of the subordinate Series I of triplets, and is a reversed group. The limits $3d^i$ of the narrow triplet series are accordingly 32,952.6, 32,771.2, and 32,390.1, on the basis of the foregoing values of $2\,p^i$ from Ritz.

In conclusion I wish to express my indebtedness to Mr. E. A. Porter for material assistance in recording the observational data.

PHYSICAL LABORATORY
UNIVERSITY OF MICHIGAN
June 1915

Reviews

Tables for Facilitating the Use of Harmonic Analysis. By H. H. Turner. London: Oxford University Press, 1913. Pp. 46. 1s.

The author's extensive work on sun-spot periodicities has led him to develop many useful short-cuts in computing. In these tables he gives the coefficients in thirteen Fourier series from nine to twenty-one terms in length. The tables are intended for "exploring" work and hence are given to two places only. Ample illustration is given of their use, with criteria for interpreting the value of any resultant periodicity. The compilation should encourage the use of harmonic analysis by anyone who is searching for possible periodicities in long series of observations.

O. J. L.

The Sun. By R. A. Sampson. Cambridge: University Press, 1914; New York: Putnam. Pp. viii+141, figs. 18. Cloth, $0.40, leather, $1.00.

This little volume of the "Cambridge Manuals of Science and Literature" presents a very acceptable résumé of the present state of our knowledge of the sun. The inspiring introduction sets forth in a telling way the part which the sun has played in the actual march of science. "Very many of our theories radiate from it and find in it, as in a great physical laboratory, their first and most striking application." Then follow chapters on "Radiation," "The Sun as the Mechanical Center of the World," "The Spectroscope," "The Sun's Surface," "Periodicity," "Eclipses," and "The Sun as a Star," which pretty well cover the whole of what assiduous research has revealed. Inaccuracies are few indeed; there are no serious omissions; it is well balanced, and written in attractive, even brilliant, style. A fair sample of nicely turned phrase is the characterization of the determination of stellar parallax, as "a debt of honor, which since the acceptance of Copernicus's theory, science is called upon to pay."

The volume might very fittingly be used in teaching, to elaborate somewhat the chapters on the sun found in the usual textbook.

P. F.

L'Astronomie. By MARCEL MOYE. Paris: O. Doin et Fils, 1913. Pp. 382, figs. in text 43, plates 4. Fr. 5.

Of the projected twenty-nine volumes of the astronomical section of the series of publications, the "Encyclopédie scientifique," this is the fourth to appear. The earlier volumes—those of Salet, Bosler, and Boquet—were of high grade, and the present work in no way departs from their standard, though from the very nature of its purpose it is radically different in style. It is the first volume of the series, the general view of the whole subject, the broad survey; its various phases find in the other volumes the technical and detailed presentation.

American teachers and students will recognize that the arrangement of the various chapters, as well as the order of matter within the chapters, is similar to that of the various textbooks of Professor C. A. Young, and is therefore excellent. The view is modern; the important recent advances are generally noted.

It is to be hoped that the war and the consequent diversion of scientific thought will not put an end to, or greatly delay, this useful series of publications.

P. F.